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An Overview of Meteorological, Sea Ice and Sea-Surface Temperature Conditions off Nova Scotia and the Gulf of Maine during 2008

Bilan des conditions météorologiques, des conditions de la glace de mer et des températures de surface de la mer au large de la Nouvelle-Écosse et dans le golfe du Maine en 2008

B. Petrie, R.G. Pettipas, and W.M. Petrie

Ocean Sciences Division, Maritimes Region
Bedford Institute of Oceanography
P.O. Box 1006, 1 Challenger Drive
Dartmouth, Nova Scotia
B2Y 4A2

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TABLE OF CONTENTS

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ABSTRACT

In 2008, the North Atlantic Oscillation (NAO) index was positive (+4.3 mb, +0.5 SD) and slightly higher than its 2007 value (+2.5 mb, +0.3 SD). Mean annual air temperatures were 0.2 to 1.3°C above normal, with the highest anomaly (1.3°C) recorded on the Magdalen Islands. The average December-June Newfoundland and Labrador sea ice cover and ice volume were 0.5 and 0.3 SD (standard deviation) below normal, respectively. The Gulf of St. Lawrence ice cover (Dec.-Apr.) in 2008 was the 20th lowest (0.1 SD below normal) and ice volume (Dec.-Apr.) was the 15th lowest (0.47 SD below normal) in the 39 year record. Below normal conditions also prevailed on the Scotian Shelf: overall the January to April coverage and volume were 0.84 (15th) and 0.42 SD (19th) below normal. Nine hundred seventy-six icebergs reached the Grand Banks in 2008, a substantial increase from 2007 when 324 were observed, and significantly greater than the long-term mean of 703. The analysis of satellite data indicates that positive sea surface temperatures (SST) anomalies prevailed throughout the region with a representative value of about +0.6°C (+0.9 SD). Twenty-two of 23 areas had positive annual SST anomalies; values ranged from 0°C (Georges Bank) to +1.4°C (Hamilton Bank). In 2008, a composite index, which combines the NAO, air temperature, ice volume, and SST observations, was the 5th warmest in the 39 year record, an increase from 2007.

RÉSUMÉ

En 2008, l'indice d'oscillation nord-atlantique (NAO) était positif (+4,3 mb, +0,5 ÉT) et légèrement supérieur à sa valeur en 2007 (+2,5 mb, +0,3 ÉT). Les températures atmosphériques moyennes annuelles s'échelonnaient entre 0,2 et 1,3 °C au-dessus de la normale, dont la température anormale la plus élevée (1,3 °C) a été enregistrée aux Îles de la Madeleine. La couverture des glaces de mer et le volume des glaces moyens mesurés entre décembre et juin à Terre-Neuve-et-Labrador se situaient de 0,5 à 0,3 ÉT (écarts type) au-dessous de la normale, respectivement. En 2008, la couverture des glaces du golfe du Saint-Laurent (de décembre à avril) était vingtième en ce qui concerne les valeurs les plus faibles (0,1 ÉT sous la normale) et le volume des glaces (de décembre à avril) était quinzième en ce qui concerne les valeurs les plus faibles (0,47 ÉT sous la normale) par rapport aux données existantes sur les 39 dernières années. On a également observé des conditions sous la normale dans le plateau néo-écossais : la couverture et le volume des glaces de janvier à avril étaient de 0,84 (15e) et d'un ÉT de 0,42 (19e) sous la normale. Neuf cent soixante-seize icebergs ont atteint les Grands Bancs en 2008, une augmentation substantielle par rapport à 2007, où on en avait observé seulement 324, et considérablement plus élevé que la moyenne à long terme de 703. L'analyse des données satellitaires indique la présence d'anomalies dans la température à la surface des mers (TSM) positive dans cette région où la valeur représentative se chiffre à environ +0,6 °C (+0,9 ÉT). Vingt-deux des 23 régions présentaient des anomalies dans la TSM annuelle; les valeurs passaient de 0 °C (banc Georges) à +1,4 °C (banc Hamilton). En 2008, l'indice composite, qui combine à la fois la NAO, la température atmosphérique, le volume des glaces et la TSM mesurés, figurait au cinquième rang des indices les plus élevés au cours des 39 dernières années, une augmentation par rapport à 2007.

INTRODUCTION

This research document discusses air temperature trends, winds, sea ice cover, iceberg drift, and sea surface temperatures (SST) during 2008 in the Northwest Atlantic, with its major focus on the Scotian Shelf and the Gulf of Maine (Fig. 1). It complements the oceanographic reviews of the waters in and around the Gulf of St. Lawrence, Newfoundland and Labrador, and the Scotian Shelf and Gulf of Maine for the Atlantic Zone Monitoring Program (AZMP; see Colbourne et al. 2009, Galbraith et al. 2009, Petrie et al. 2009). Environmental conditions are compared with the long-term means and, in some cases, to 2007 values. These comparisons are often expressed as anomalies, which are the deviations from the long-term means, or as standardized anomalies, i.e. the anomaly divided by the standard deviation (SD). If the data permit, the long-term means and standard deviations are calculated for the 30-year base period, 1971-2000. The use of standardized anomalies and the same base period allow direct comparison of anomalies among sites and variables.

METEOROLOGICAL OBSERVATIONS

Air Temperatures

Monthly surface air temperature anomalies relative to the 1968-1996 means for the North Atlantic Ocean are available from the US National Oceanic and Atmospheric Administration (NOAA) interactive website at http://www.cdc.noaa.gov/cgi-bin/data/getpage.pl. The annual anomalies are within 0.5°C of normal values over the central Labrador Sea, the southern Gulf of St. Lawrence, the Scotian Shelf, and the Gulf of Maine. The northern Gulf of St. Lawrence, Labrador Shelf, and the Grand Banks are 0.5 to 1.0°C above normal (Fig. 2A). The seasonal maps indicate strong fluctuations throughout the year, with the outstanding feature an intense cold anomaly (to -4.5°C) centered over the Labrador Sea during the winter (Fig. 2B). This anomaly was a prime factor in the renewal of deep convection in the Labrador Sea to depths of 1800 m (Våge et al. 2008). It is reflected in the seasonal anomalies in the sites bordering the Labrador Sea (Table 1).

Table 1. Seasonal temperature anomalies for stations bordering the Labrador Sea.

	Seasonal Air Temperature Anomalies			
Site	JFM[1]	AMJ[2]	JAS[3]	OND[4]
Nuuk	-1.8	2.6	1.5	0.5
Iqaluit	-1.8	2.8	0.9	-0.7
Cartwright	-1.1	1.2	2.1	0.9
St. John's	0.6	-0.3	1.7	2.2

[1]JFM = January, February, March
[2]AMJ = April, May, June
[3]JAS = July, August, September
[4]OND = October, November December

Monthly air temperature anomalies for 2007 and 2008 relative to their 1971-2000 mean at 6 sites in the Scotian Shelf-Gulf of Maine region are shown in Fig. 3. The anomalies are presented in 2 ways: the heights of the bars represent the anomalies in °C; the colours of the bars represent the number of standard deviations the anomalies differ from their long-term means. Data from the Canadian sites were from the Environment Canada website and for non-Canadian locations from *Monthly Climatic Data for the World* (NOAA 2008). The observed and normalized anomalies for these stations and for a more broadly distributed group are listed in

Table 2. In 2008, annual air temperature anomalies were positive at all sites; they ranged from +0.2 to +0.8°C in the Scotian Shelf-Gulf of Maine region (Table 2). The time series of annual anomalies indicates that most sites feature increasing temperatures over the long-term with decadal scale variability superimposed. For shorter periods, this can lead to no trend or decreasing temperatures (Fig. 4). Linear trends from 1900 to present from Boston, Shearwater, and Sydney correspond to changes of +1.7°C, +1.4°C, and 1.0°C, respectively; the change for the shorter Sable Island record (1915-present) corresponds to +1.1°C if extrapolated from 1900 to present.

Table 2. Air temperature statistics 2008 (Standard Deviation (SD)).

Site	Annual Anomaly 2008 (°C)		SD of Monthly Anomalies 2008 (°C)	1971-2000 Annual	
	Observed	Normalized		Mean (°C)	SD (°C)
Nuuk	+0.7	+0.6	2.1	-1.77	1.22
Iqaluit	+0.6	+0.4	2.2	-9.70	1.55
Cartwright	+0.8	+0.7	1.6	-0.54	1.12
St. John's	+1.0	+1.4	1.3	4.67	0.77
Magdalen I.	+1.3	+1.7	1.3	4.72	0.80
Sydney	+0.8	+1.1	1.3	5.53	0.76
Sable I.	+0.5	+0.7	1.1	7.61	0.68
Shearwater	+0.6	+0.8	1.0	6.67	0.67
Yarmouth	+0.7	+1.2	0.8	6.95	0.57
Saint John	+0.6	+0.9	0.8	5.02	0.67
Boston	+0.2	+0.3	0.9	10.88	0.57
Cape Hatteras	+0.4	+0.6	1.2	17.06	0.70

Focussing on the air temperatures for the 6 Scotian Shelf-Gulf of Maine sites, the anomalies, summarized in Fig. 5(A), illustrate 2 points: for most years the anomalies have the same sign; i.e. the stacked bars and the scatter plot coincide. Since 1915, when all sites were operating, 72 of the 94 years had 4 or more stations with the annual anomalies having the same signs; for 49 years, all 6 stations had anomalies with the same sign. This indicates that the spatial scale of the air temperature patterns is greater than the largest spacing among sites. In fact, plotting the correlations between annual anomalies against station spacings yields an e-folding scale of 1800 km (Fig. 5B). Second, the time scale of the dominant variability has been changing from longer periods for 1915-1954 to shorter periods for 1955-2008 (Fig. 5C).

North Atlantic Oscillation (NAO) Index

The NAO index is the difference in winter (December, January, and February) sea level atmospheric pressures between the Azores and Iceland (Rogers 1984), and is a measure of the strength of the winter westerly winds over the northern North Atlantic. It represents the dominant, large scale meteorological forcing over the North Atlantic Ocean. Specifically, the index was calculated using observed sea level pressures at Ponta Delgada (up to 1997), Santa Maria (1998-2005) or Lajes (since 2006) in the Azores, and at Akureyri in Iceland. The small number of missing data early in the time series was filled using pressures from nearby stations. The NAO anomalies were calculated by subtracting the 1971-2000 mean.

A high NAO index corresponds to a deepening of the Icelandic Low and a strengthening of the Azores High. Strong northwest winds, cold air and sea temperatures, and heavy ice in the

Labrador Sea area are usually associated with a high positive NAO index (Colbourne et al. 1994; Drinkwater 1996). The opposite response occurs during years with a negative NAO index.

The NAO has been shown to strongly affect bottom temperature distributions throughout the region from the Labrador Shelf to the Gulf of Maine (Petrie 2007). The response is bimodal, the product of direct and advective effects, with positive (negative) NAO generally corresponding to colder (warmer) than normal bottom temperatures over the Labrador-Newfoundland Shelf, the Gulf of St. Lawrence, and the eastern Scotian Shelf, and warmer (colder) than normal conditions on the central and western Scotian Shelf and in the Gulf of Maine.

In 2008, the winter NAO index was positive and within 0.5 SD of the long-term normal value (+4.3 mb, 0.5 SD above normal), an increase from the +2.5 mb anomaly in 2007 (Fig. 6). Six of the last 7 years have featured weak anomalies, i.e. within 0.5 SD of the long-term mean. The greatest immediate response to the NAO and associated forcing in 2008 appears to have occurred in the Labrador Sea. There, the positive wintertime NAO index was accompanied by a strong, negative air temperature and heat flux anomaly (Fig. 3; Våge et al. 2008), leading to deep (to 1800 m) convection. The resulting cold water mass could affect the adjacent continental shelf areas in the next 1-3 years.

Winds

The Sable Island wind speed and wind stress components along- (60°T) and across-shore (150°T) in 2008 are shown in Fig. 7 and compiled in Table 3 as monthly means. Several studies have indicated the importance of wind in initiating and ending blooms on the Scotian Shelf (Greenan et al. 2002, 2004, 2008).

Table 3. Wind stress statistics, Sable Island 2008. Anomalies and standard deviations based on 1971-2000 observations.

	Along-shore Stress (Pa)	Normalized Along-shore Stress Anomaly	Across-shore Stress (Pa)	Normalized Across-shore Stress Anomaly
Annual	0.014	-0.58	0.01	-0.71
January	0.041	-0.19	0.019	-0.64
February	0.056	+0.84	-0.001	-1.3
March	0.015	-0.03	0.075	+2.1
April	-0.008	-0.29	0.01	+0.2
May	-0.022	-1.57	-0.004	+0.29
June	0.005	-0.64	0	+0.99
July	0.021	+0.14	-0.016	-0.37
August	0.008	-0.51	-0.003	+0.05
September	0.011	-0.37	-0.008	-1.5
October	-0.009	-1.04	0.024	+0.22
November	0.025	-0.04	-0.004	-1.9
December	0.08	-0.94	0.007	-1.3

In 2008, both components of monthly stress were weaker in the upwelling favourable direction compared to the long-term means. The long-term and 2008 Ekman contribution of the annual along-shore wind stress to flushing the shelf can be estimated: the long-term mean Ekman flux is equivalent to 32% of the Shelf volume; in 2008, along-shore stress would account for slightly less, viz., 28% of the Shelf volume. However, it is apparent that there were numerous events of

shorter duration that could have effected blooms. These events may have had more impact than a steady, weak stress component.

SEA ICE OBSERVATIONS

The spatial distribution and concentrations of sea ice are available from the daily ice charts published by the Canadian Ice Service (CIS) of Environment Canada in Ottawa, Ontario. The current year's ice statistics with the long-term median, maximum, and minimum positions of the ice edge (concentrations above 10%) based on the 1971-2000 data (Canadian Ice Service 2002) are compared. Also included is an analysis of the time of onset, duration, and last presence of sea ice based upon the sea ice database maintained at the Bedford Institute of Oceanography (Dartmouth, Nova Scotia) for the Newfoundland region (Peterson and Prinsenberg 1990) and for the Gulf of St. Lawrence and the Scotian Shelf (Drinkwater et al. 1999). In the current analysis, ice concentrations of ≥1 tenth were sampled at 0.1 by 0.1 degree intervals from the CIS weekly composite ice charts for the period 1969-2008. A climatology (1971-2000) of first and last appearance and duration was generated for each grid point and was subtracted from the values determined for 2008. Grid points for which the climatology had less than 5 years with data or where the duration was <10 days were excluded from further analysis. Ice areas, extents, and volumes were computed using the CIS weekly composite GIS formatted charts available from the CIS website: http://ice-glaces.ec.gc.ca/App/WsvPageDsp.cfm?Lang=eng&lnid=3&ScndLvl=no&ID=11715. In previous years, a 0.5 by 1.0 degree latitude-longitude grid was used, but this exaggerated the ice extent significantly.

Ice cover provides an index that can be related to the initiation and maintenance of the spring phytoplankton bloom. On the other hand, identical ice cover but differing thickness, leading to different ice volumes, could distinguish a winter with above or below normal heat losses. Since observations of ice thickness are not available, ice volumes have been estimated for the 3 regions using a look up table that assigns characteristic thicknesses to particular ice types. While this is not an ideal way to estimate ice volumes, it does provide a basic assessment that can be used as an additional climate index and a reference point for testing ice models. The Canadian Ice Service does not generally compute ice volume estimates for Canadian waters. They give 2 main reasons for this (S. McCourt, pers. Comm..; steve.mccourt@ec.gc.ca): "1. Ice types are reported in terms of "stage of development" which have an associated range of thickness. For example "first-year ice" has an associated range of thickness of 30 cm to 120 cm. It is therefore difficult to assign a "typical" thickness and in the case of first-year ice, the value assigned will vary from area to area (i.e. first-year ice in the Gulf would have a different thickness than first-year ice in the Arctic). 2. Old ice in particular is extremely difficult to estimate thickness and subsequent volume, however, for the Gulf of St Lawrence this should not be a limiting factor."

Newfoundland and Labrador

Sea Ice. Throughout the ice season in 2008, the sea ice area was generally within 0.5 SD of the long-term mean coverage (November to April), or approximately 1 SD less than the long-term distribution during the low ice cover months of May and June (Fig. 8A, B; Table 4). The ice volume time series showed a similar variation (Fig. 9; Table 5). Ice area and volume (Dec.-June) for 2008 were below normal by approximately 0.5 and 0.3 SD, the 13th year with less than average areas and volumes. This places the past year roughly in the centre of the ice area and volume distribution, with 2008 ranking the 24th least area and the 21st least volume in 39 years.

Ice appeared along the Labrador coast and at the mouth of Belle Isle Strait from mid-December to 1 January 2008 (days -15 and 0, upper panel Fig. 10); it reached the northern Avalon Peninsula by mid-March (day 75). Relative to the long-term mean, ice appearance typically varied from normal (0 contour, lower panel Fig. 10) to approximately 15 days later than normal over most of the Newfoundland and Labrador Shelf region. Ice began to disappear from the area just north of Grand Bank in late-March, early April (day 105; Fig. 11). It began to retreat from northern Newfoundland waters and southern Labrador in early May (day 120). Ice persisted in the most northern part of the analysis region until mid-May (day 135). Over much of the Newfoundland and Labrador Shelf, it disappeared about 2 weeks earlier than normal (positive anomalies colour coded red, Fig. 11, lower panel).

Table 4. Ice Area statistics, Newfoundland-Labrador.

Month	07-08 Ice Year (km^2)	1971-2000 Mean (km^2)	Anomaly (km^2)	Normalized
November	14	120	-110	-0.30
December	15400	16300	-900	-0.05
January	95000	109000	-15000	-0.22
February	183000	220000	-38000	-0.54
March	190000	217000	-26000	-0.38
April	132000	125000	+7000	+0.14
May	23000	66000	-43000	-0.97
June	500	22000	-22000	-0.81

Table 5. Ice Volume statistics, Newfoundland-Labrador.

Month	07-08 Ice Year (km^3)	1971-2000 Mean (km^3)	Anomaly (km^2)	Normalized
November	0	0	0	-0.29
December	1.8	2.4	-0.6	-0.22
January	22	27	-5	-0.27
February	56	75	-19	-0.62
March	107	108	-1	-0.03
April	118	94	+25	0.53
May	23	59	-36	-0.88
June	0.6	22	-21	-0.84

The duration of sea ice is the number of days that ice, with a minimum concentration of 10%, is present. It is not simply the date of the first presence minus the last presence, because the ice may disappear from an area for a time and then reappear. In 2008, the duration ranged from less than 30 days north of Grand Bank to over 130 days along the Labrador coast (Fig. 12, upper panel). The 2008 pattern, with ice present for generally 0-15 days less than normal (Fig. 12, lower panel), differs from 2007 when ice lasted 10-20 days longer than normal.

Icebergs. The International Ice Patrol of the United States Coast Guard monitors the number of icebergs that pass south of 48°N latitude each year. Since 1983, data have been collected with SLAR (Side-Looking Airborne Radar). The 1985-2008 period is considered to have reliable SLAR measurements. During the 2007/2008 iceberg season (October 2007 to September 2008), 976 icebergs were detected south of 48°N, an increase from 2007, when 324 were observed and substantially more than the 1985-2008 mean of 703 (Fig. 13).

Gulf of St. Lawrence

The locations of the ice edge within the Gulf of St. Lawrence during the 2007-2008 winter season are shown in Fig. 14, the ice areas and volumes in Fig. 15, and the ice statistics are tabulated in tables 6 and 7. The most extensive ice cover and volume occurred from January to April, with below normal coverage and volume in January and February and above normal coverage in March. For most of the Gulf, ice appearance was 0-15 days later than normal (Fig. 10), lasted 0-15 days longer than normal (Fig. 11), and consequently, ice duration was, for the greater part, close to normal (Fig. 12). The exception was off the southwest coast of Newfoundland, where ice duration was about 1 month longer than normal. For the 39 year time series, the ice cover (Dec.-Apr.) ranked 20th (0.1 SD below normal; the least area ranking first), but perhaps more significantly (the Gulf cover is limited by its boundaries), 15th (0.47 SD below normal) in volume.

Table 6. Ice area statistics, Gulf of St. Lawrence.

Month	07-08 Ice Year (km^2)	1971-2000 Mean (km^2)	Anomaly (km^2)	Normalized
November	52	5	+47	+1.71
December	8400	12600	-4300	-0.35
January	77000	111000	-34000	-0.88
February	170000	189000	-19000	-0.75
March	179000	151000	+28000	+0.64
April	37000	45000	-8000	-0.26
May	1250	6300	-5100	-0.75
June	2	590	-590	-0.41

Table 7. Ice volume statistics, Gulf of St. Lawrence.

Month	07-08 Ice Year (km^3)	1971-2000 Mean (km^3)	Anomaly (km^2)	Normalized
November	0.0	0	+0.0	+0.04
December	1.3	1.7	-0.5	-0.25
January	9.5	19	-9.8	-1.15
February	33.3	50	-16.7	-1.27
March	60.6	58.1	+2.5	+0.11
April	25.3	27.9	-2.6	-0.12
May	1.3	5.17	-3.9	-0.73
June	0.0	0.57	-0.6	-0.42

Scotian Shelf

The greater part of sea ice on the Scotian Shelf originates in the Gulf of St. Lawrence, and is transported through Cabot Strait pushed by northwesterly winds and ocean currents. Sydney Bight and the southern coast of Cape Breton are typically the only areas heavily affected by ice. The ice areas and volumes are shown in Fig. 16 and compiled in tables 7 and 8. The heaviest months, January to April, featured below normal coverage and volumes from January to March, and above normal values in April. Overall, the January to April coverage and volume were 0.84 (15th) and 0.42 SD (19th) below normal.

Table 7. Ice Area statistics, Scotian Shelf.

Month	07-08 Ice Year (km^2)	1971-2000 Mean (km^2)	Anomaly (km^2)	Normalized
January	100	1600	-1500	-0.56
February	3100	14000	-10000	-1.04
March	7200	18000	-10000	-0.84
April	7300	6000	+1600	+0.31

Table 8. Ice Volume statistics, Scotian Shelf.

Month	07-08 Ice Year (km^3)	1971-2000 Mean (km^3)	Anomaly (km^2)	Normalized
January	0.0	0.2	-0.2	-0.59
February	0.7	3.4	-2.7	-1.03
March	4.1	7.2	-3.1	-0.62
April	5.9	3.5	+2.3	+0.69

REMOTELY-SENSED SEA SURFACE TEMPERATURE

A 9 km resolution Pathfinder sea surface temperature database is maintained at BIO. In the following analysis, the 18 km resolution Multi-Channel Sea Surface Temperature (MCSST) data from 1999 was substituted for the Pathfinder observations from that year, because there was serious degradation of the latter, particularly towards the end of the year. This deterioration of the Pathfinder data quality was not evident in other years, nor was it found for the MCSST data. The Pathfinder dataset runs to June 2003, when this version of the data series was terminated. To provide data for June 2003 to present, the sea surface temperature data (1997-present) downloaded from the satellites by the remote sensing group in the Ocean Research and Monitoring Section (ORMS) was used. Comparison of the Pathfinder and ORMS temperatures during the common time period led to a conversion equation SST(Pathfinder)= 0.976*SST(ORMS)+0.46 with an r^2=0.98. The ORMS observations were adjusted to bring them in line with the longer Pathfinder series. Anomalies were based on 1985-2008 averages.

Annual anomalies for 23 subareas, stretching from the Labrador Sea to the Gulf of Maine (Fig. 17), were determined from the averages of monthly anomalies, and arranged from north to south (Fig. 18; Table 9). In 2008, anomalies ranged from 0°C (0 SD) over Georges Bank to +1.4°C (+2.1 SD) over Hamilton Bank. Twenty-two of the 23 areas had positive anomalies, 20 were greater than +0.5 SD. The average anomaly was 0.9°C over the Labrador Shelf, +0.7°C over the Newfoundland Shelf, +0.8°C in the Gulf of St. Lawrence, and +0.4°C over the Scotian Shelf.

Table 9. Sea surface temperature (SST) anomalies, 2008, and long-term SST statistics. The highest and lowest anomalies are highlighted.

Site	2008 SST Anomaly (°C)	2008 SST Anomaly Normalized	1985-2008 Mean Annual SST (°C)	1985-2008 SST Std. Dev. (°C)
Bravo, Labrador Sea	+0.9	+1.3	4.63	0.72
Hudson Strait	+0.4	+0.9	-0.20	0.42
Nain Bank	+1.0	+1.4	0.69	0.73
Hamilton Bank	**+1.4**	+2.1	1.63	0.68
St. Anthony Basin	+1.1	+1.5	2.82	0.76
NE Nfld Shelf	+1.0	+1.3	3.73	0.73
Avalon Chn	+0.6	+0.9	5.30	0.72
Hibernia	+0.7	+0.7	5.86	0.97
SE Shoal	+0.7	+0.7	7.42	0.99
Flemish Pass	+0.5	+0.6	6.13	0.87
Green-St. Pierre Bank	+0.6	+0.9	6.33	0.68
NE Gulf of St. Lawrence	+1.1	+1.4	5.00	0.74
NW Gulf of St. Lawrence	+1.0	+1.8	4.75	0.54
Gulf of St. Lawrence Estuary	+0.4	+1.2	4.72	0.29
Magdalen Shlw	+0.8	+1.3	6.49	0.58
Cabot Strait	+0.6	+1.0	6.11	0.65
Eastern Scotian Shelf(ESS)	+0.4	+0.6	7.32	0.71
Central Scotian Shelf (CSS)	+0.3	+0.5	8.82	0.66
Western Bank	+0.4	+0.6	9.26	0.70
Western Scotian Shelf (WSS)	+0.3	+0.6	8.57	0.56
Lurcher Shoal	+0.1	+0.1	7.77	0.57
Bay of Fundy	+0.4	+0.7	7.85	0.51
Georges Bank	**-0.0**	-0.0	10.59	0.56

SUMMARY

In 2008, the NAO index was positive (+4.3 mb, +0.5 SD) and slightly higher than its 2007 value (+2.5 mb, +0.3 SD). Mean annual air temperatures were 0.2 to 1.3°C above normal, with the highest anomaly (+1.3°C) registered on the Magdalen Islands. The average December-June Newfoundland and Labrador sea ice cover and ice volume were 0.5 and 0.3 SD below normal, respectively. The Gulf of St. Lawrence ice cover (Dec.-Apr.) in 2008 was the 20th lowest (0.1 SD below normal) and ice volume (Dec-Apr) was the 15th lowest (0.5 SD below normal) in the 39 year record. Below normal conditions also prevailed on the Scotian Shelf: overall the January to April coverage and volume were 0.8 (15th) and 0.4 SD (19th) below normal. Nine hundred seventy-six icebergs reached the Grand Banks in 2008, a substantial increase from 2007 when 324 were observed, and significantly greater than the long-term mean of 703. The analysis of satellite data indicates that positive SST anomalies prevailed throughout the region with a representative value of approximately +0.6°C (+0.9 SD). Twenty-two of 23 areas had positive annual SST anomalies; values ranged from 0°C (Georges Bank) to +1.4°C (Hamilton Bank).

Table 9. Sea surface temperature (SST) anomalies, 2008, and long-term SST statistics. The highest and lowest anomalies are highlighted.

Site	2008 SST Anomaly (°C)	2008 SST Anomaly Normalized	1985-2008 Mean Annual SST (°C)	1985-2008 SST Std. Dev. (°C)
Bravo, Labrador Sea	+0.9	+1.3	4.63	0.72
Hudson Strait	+0.4	+0.9	-0.20	0.42
Nain Bank	+1.0	+1.4	0.69	0.73
Hamilton Bank	+1.4	+2.1	1.63	0.68
St. Anthony Basin	+1.1	+1.5	2.82	0.76
NE Nfld Shelf	+1.0	+1.3	3.73	0.73
Avalon Chn	+0.6	+0.9	5.30	0.72
Hibernia	+0.7	+0.7	5.86	0.97
SE Shoal	+0.7	+0.7	7.42	0.99
Flemish Pass	+0.5	+0.6	6.13	0.87
Green-St. Pierre Bank	+0.6	+0.9	6.33	0.68
NE Gulf of St. Lawrence	+1.1	+1.4	5.00	0.74
NW Gulf of St. Lawrence	+1.0	+1.8	4.75	0.54
Gulf of St. Lawrence Estuary	+0.4	+1.2	4.72	0.29
Magdalen Shlw	+0.8	+1.3	6.49	0.58
Cabot Strait	+0 6	+1.0	6.11	0.65
Eastern Scotian Shelf(ESS)	+0.4	+0.6	7.32	0.71
Central Scotian Shelf (CSS)	+0.3	+0.5	8.82	0.66
Western Bank	+0.4	+0.6	9.26	0.70
Western Scotian Shelf (WSS)	+0.3	+0.6	8.57	0.56
Lurcher Shoal	+0.1	+0.1	7.77	0.57
Bay of Fundy	+0.4	+0.7	7.85	0.51
Georges Bank	-0.0	-0.0	10.59	0.56

SUMMARY

In 2008, the NAO index was positive (+4.3 mb, +0.5 SD) and slightly higher than its 2007 value (+2.5 mb, +0.3 SD). Mean annual air temperatures were 0.2 to 1.3°C above normal, with the highest anomaly (+1.3°C) registered on the Magdalen Islands. The average December-June Newfoundland and Labrador sea ice cover and ice volume were 0.5 and 0.3 SD below normal, respectively. The Gulf of St. Lawrence ice cover (Dec.-Apr.) in 2008 was the 20th lowest (0.1 SD below normal) and ice volume (Dec-Apr) was the 15th lowest (0.5 SD below normal) in the 39 year record. Below normal conditions also prevailed on the Scotian Shelf: overall the January to April coverage and volume were 0.8 (15th) and 0.4 SD (19th) below normal. Nine hundred seventy-six icebergs reached the Grand Banks in 2008, a substantial increase from 2007 when 324 were observed, and significantly greater than the long-term mean of 703. The analysis of satellite data indicates that positive SST anomalies prevailed throughout the region with a representative value of approximately +0.6°C (+0.9 SD). Twenty-two of 23 areas had positive annual SST anomalies; values ranged from 0°C (Georges Bank) to +1.4°C (Hamilton Bank).

A graphical summary of selected time series shows considerable variability; for example, 1972-1975 and 1985-1993 were predominantly colder than normal and 1998-2006 was warmer than normal (Fig. 19, upper panel). During the past year, 21 of the 23 series had positive anomalies; 7 were within 0.5 SD of normal and 16 were greater than 0.5 SD above normal. This represents a small, positive change from 2007.

The mosaic plot can be summarized as a combination bar and line-scatter plot (Fig. 19, lower panel). Variables are colour coded so that systematic spatial variability can be seen. The height of each variable's contribution to the bar depends on its magnitude. Positive components are stacked on the positive side, the negative components on the negative side. The sum of the normalized anomalies (difference between the positive and negative stacks) is shown as a black line connecting grey circles. (Note that the sum for the SST variables for 1970-1984 was estimated from the linear regression between the SST sum and the sum of the other variables for the 1985-2005 period (r^2=0.73).) This is a measure of whether the year tended to be colder or warmer than normal, and can serve as an overall climate index. The cold periods of 1972-1975 and 1985-1993 and the warm period of 1998-2008 are apparent. In 2008, this composite index was the 5th warmest in the 39 year record, an increase from 2007.

ACKNOWLEDGEMENTS

We thank all those who provided data, especially Ingrid Peterson of the Bedford Institute of Oceanography for the monthly areal ice extent data for the Newfoundland region. We also thank Eugene Colbourne and Peter Galbraith for reviewing the document.

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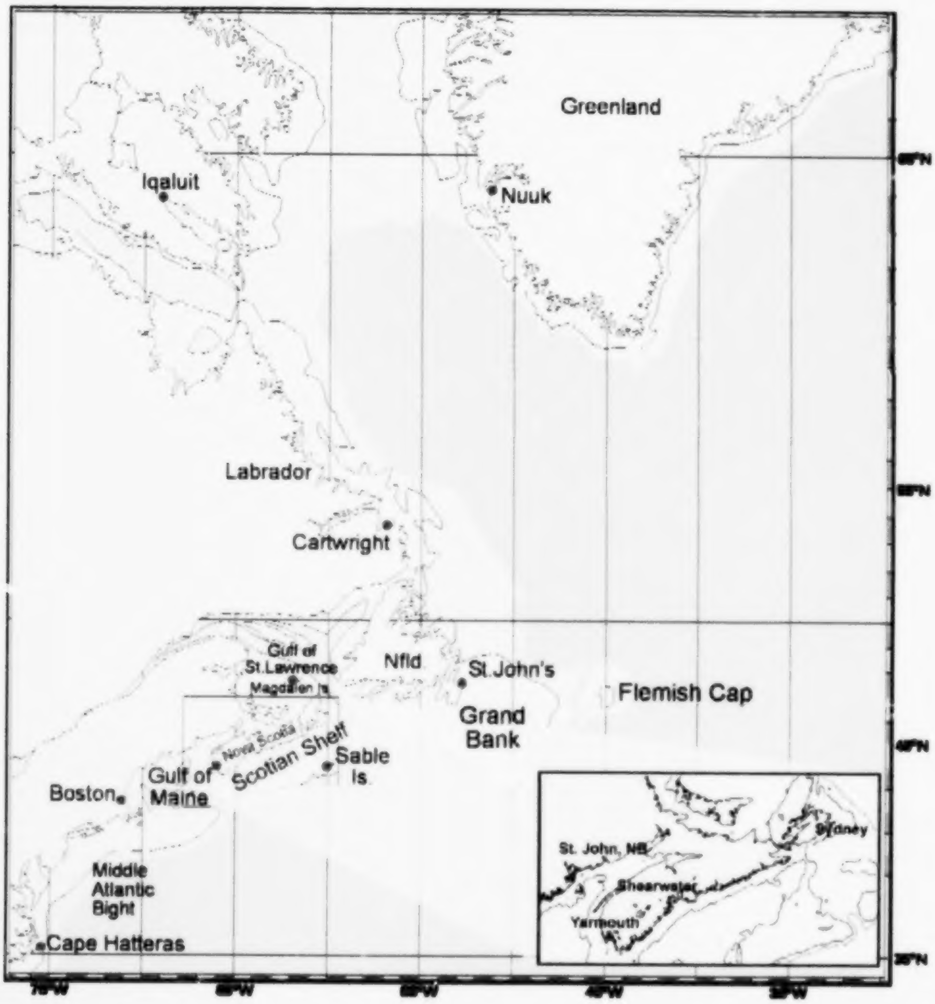


Fig. 1. Northwest Atlantic showing coastal air temperature stations. The shading differences denote the 200 m and 1000 m isobaths.

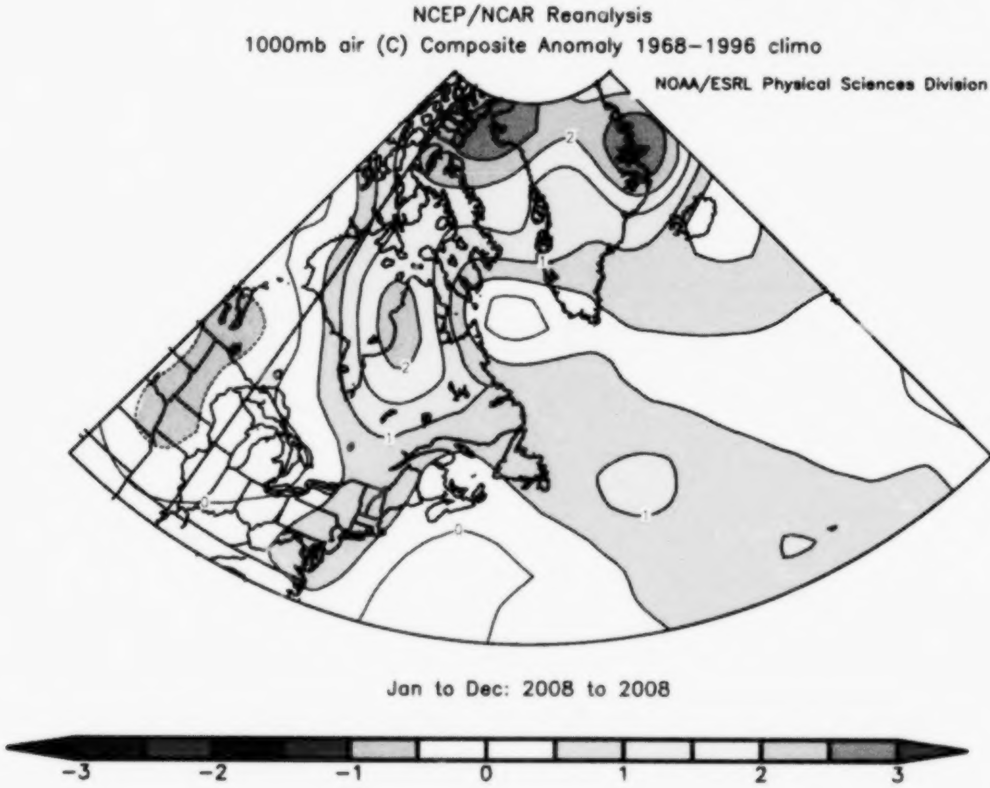


Fig. 2A. The 2008 annual air temperature anomaly (°C) over the Northwest Atlantic relative to the 1968-1996 means, from http://www.cdc.noaa.gov/cgi-bin/data/getpage.pl.

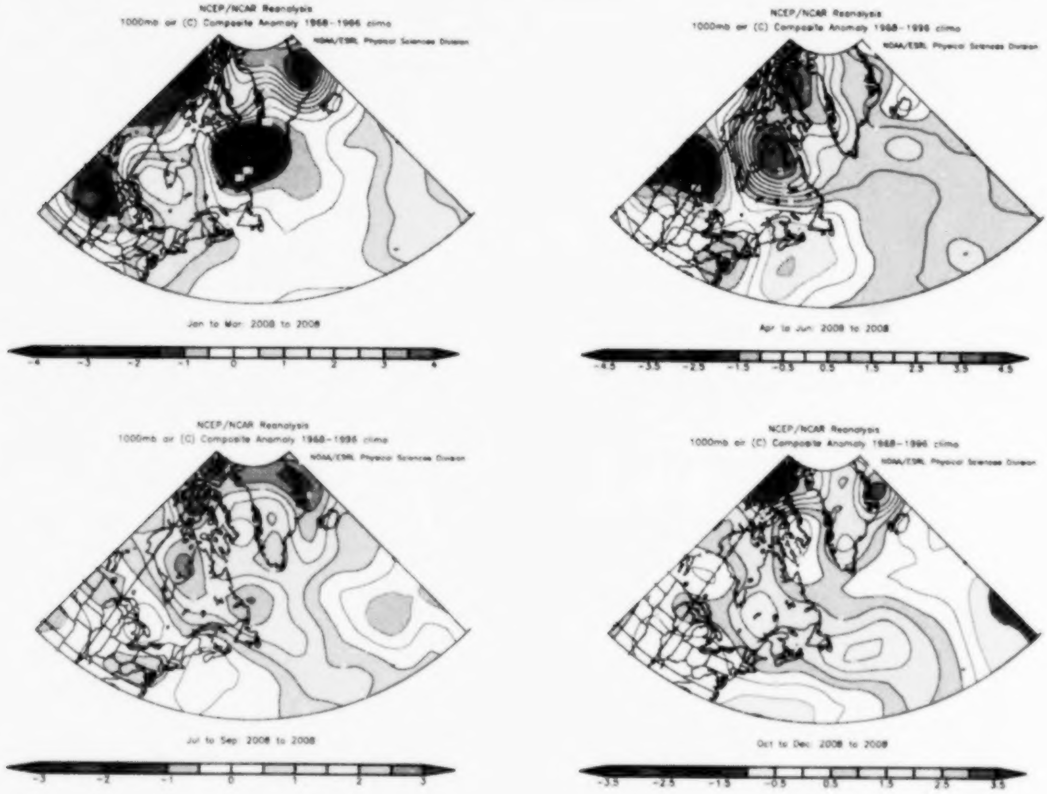


Fig. 2B. Seasonal air temperature anomalies (°C) over the Northwest Atlantic for winter (JFM), spring (AMJ), summer (JAS), and fall (OND) 2008 relative to their 1968-1996 means.

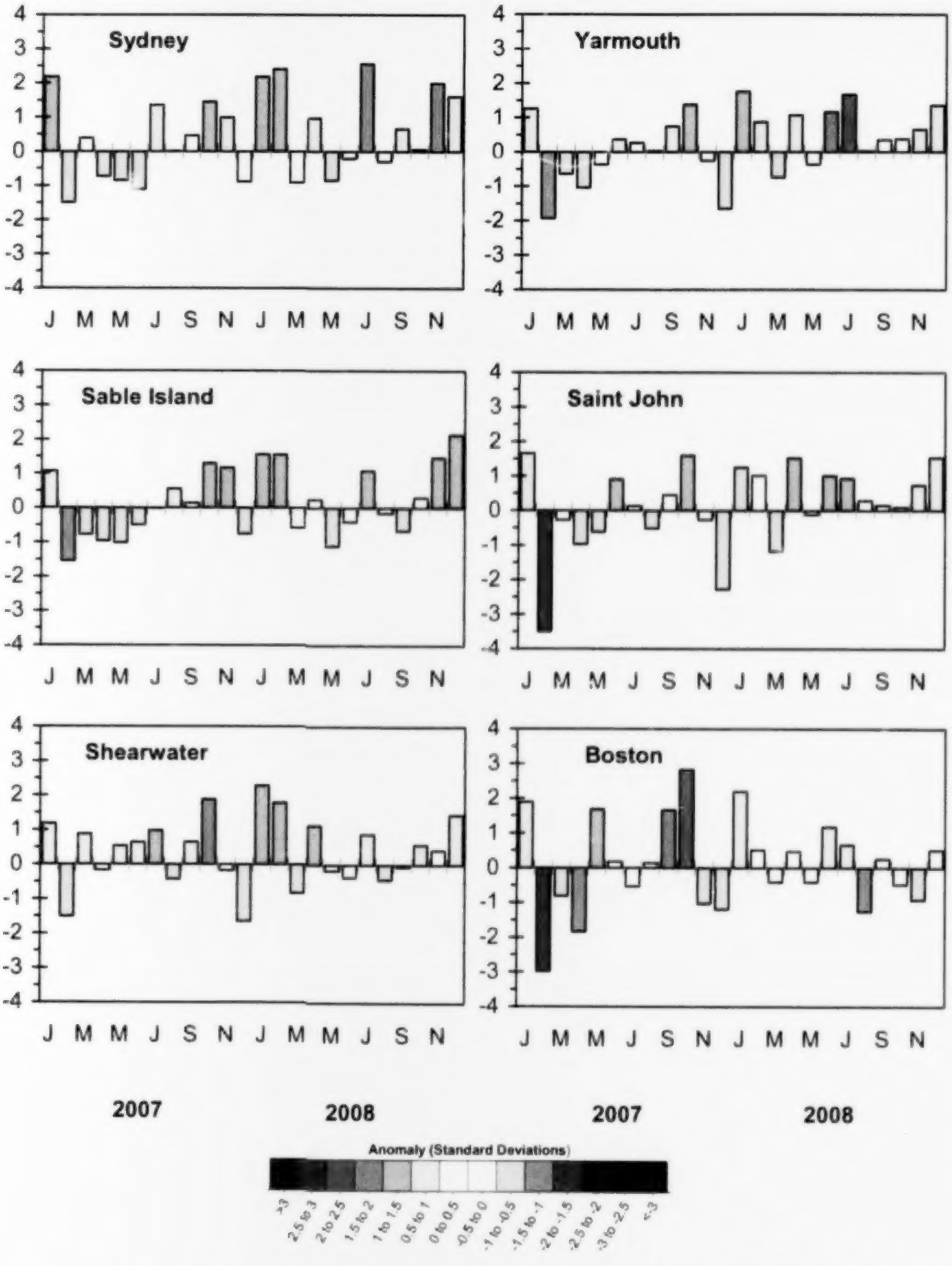


Fig. 3. Monthly air temperature anomalies in 2007 and 2008 at coastal sites in Scotian Shelf-Gulf of Maine region (see Fig. 1 for locations). Anomalies are colour coded in terms of the numbers of Standard Deviation (SD) above or below normal.

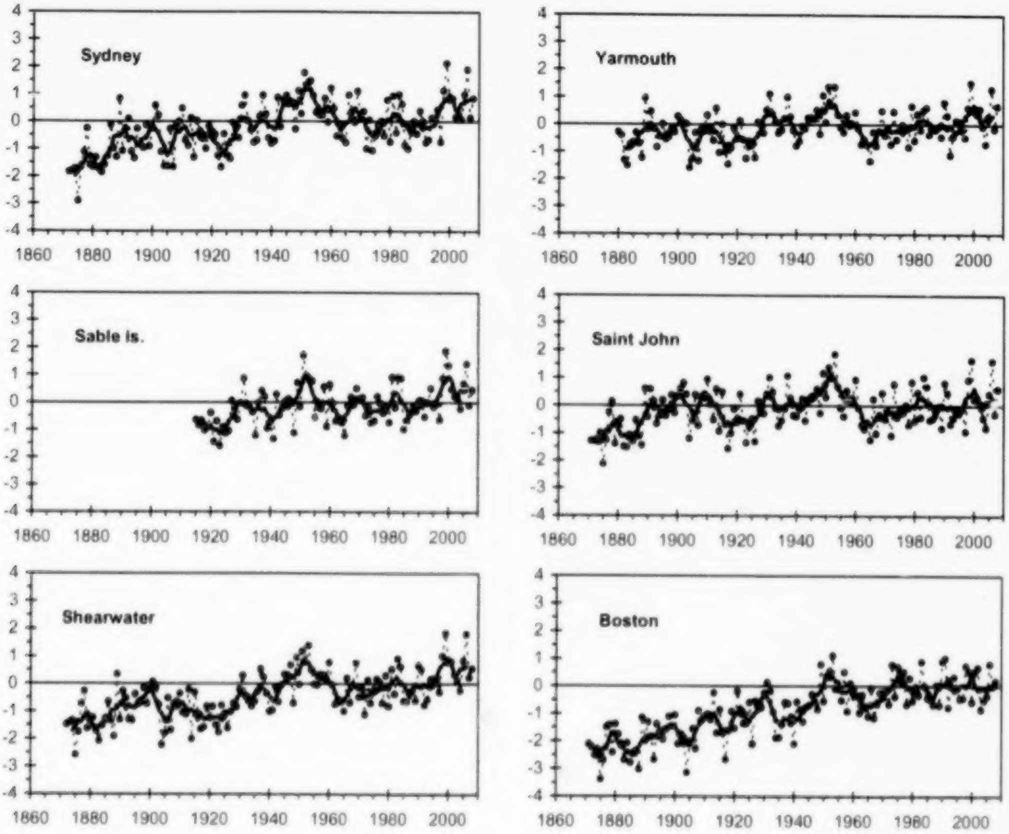


Fig. 4. Annual air temperature anomalies (dashed line) and 5-year running means (solid line) at selected sites in Scotian Shelf-Gulf of Maine region.

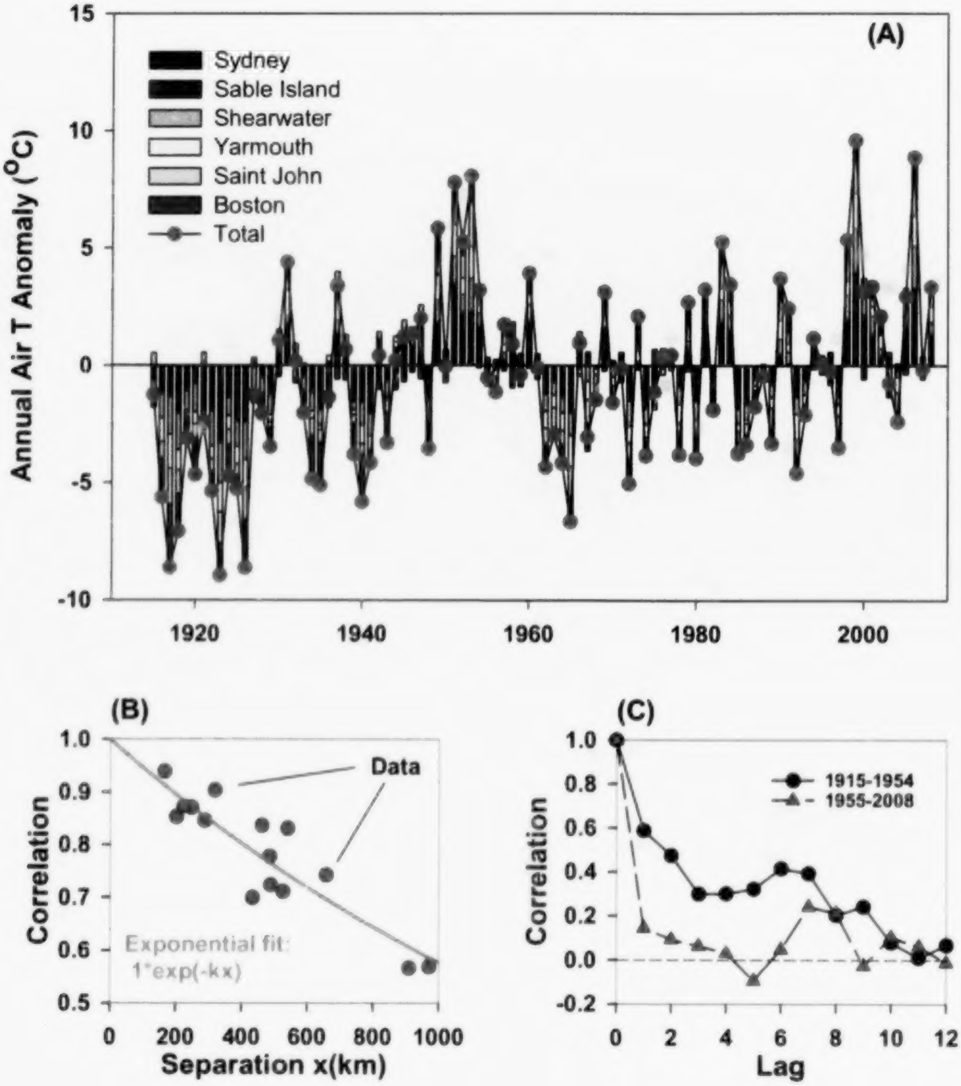


Fig. 5. (A)The contributions of each of the annual temperature anomalies for 6 Scotian Shelf-Gulf of Maine sites are shown as a bar chart, and their summation as a time series (grey circles, black line). (B) Variations of the correlations of the annual temperature anomalies with station separation. (C) The autocorrelation of the average annual temperature anomaly for the 6 sites.

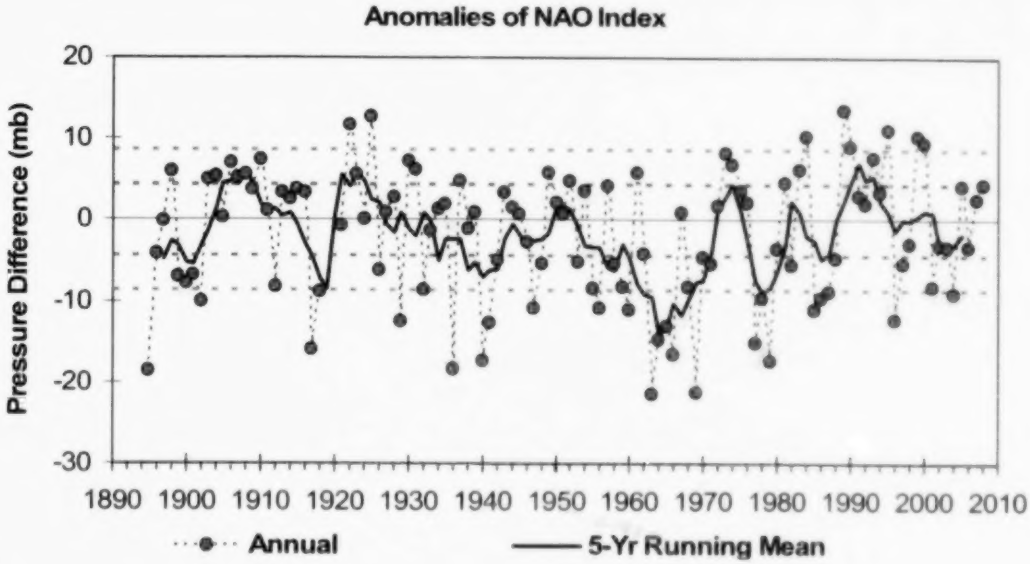


Fig. 6. Anomalies of the North Atlantic Oscillation index, defined as the winter (December, January, February) sea level pressure difference between the Azores and Iceland, relative to the 1971-2000 mean. The 0.5 (green broken lines) and 1.0 (red) standard deviations are shown.

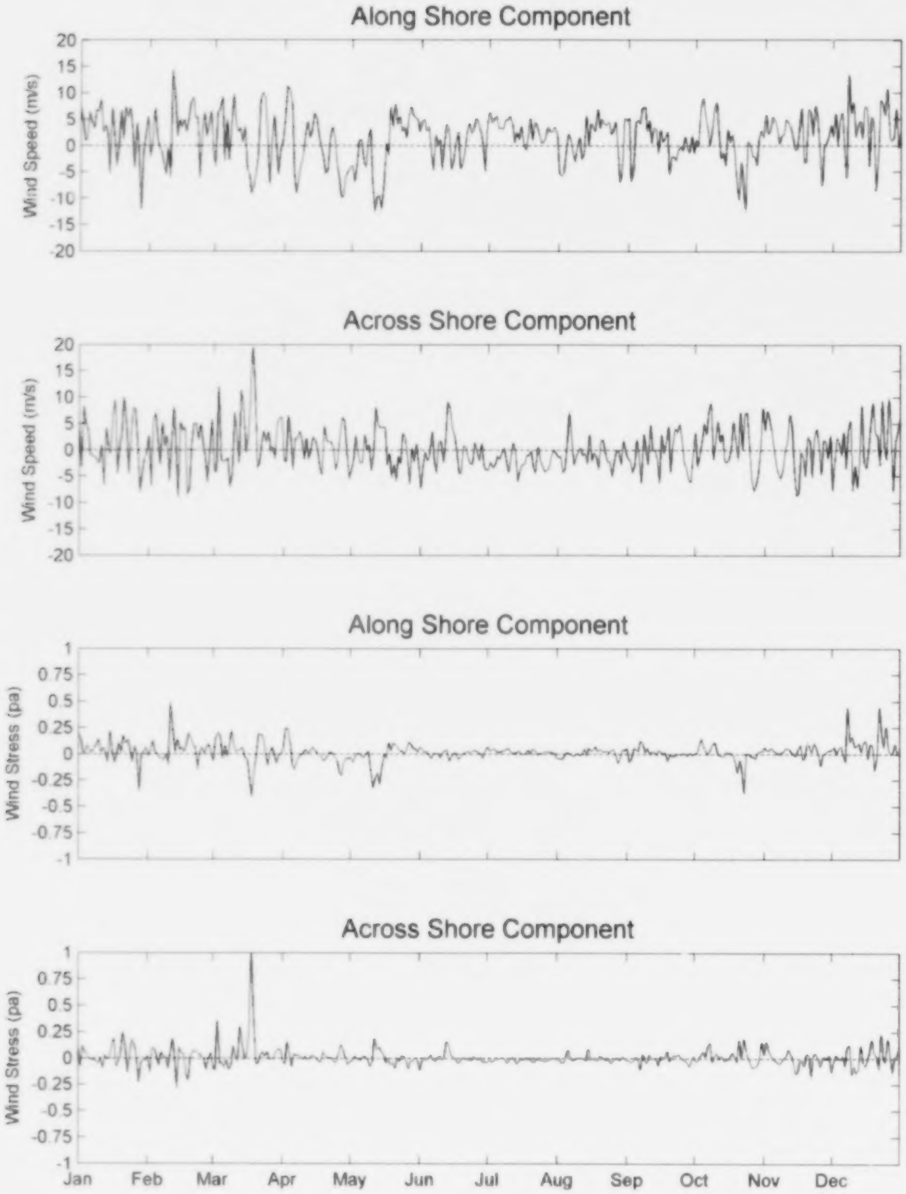


Fig. 7. The Sable Island along- (60°T) and across- (150°T) shore wind and wind stress components for 2008.

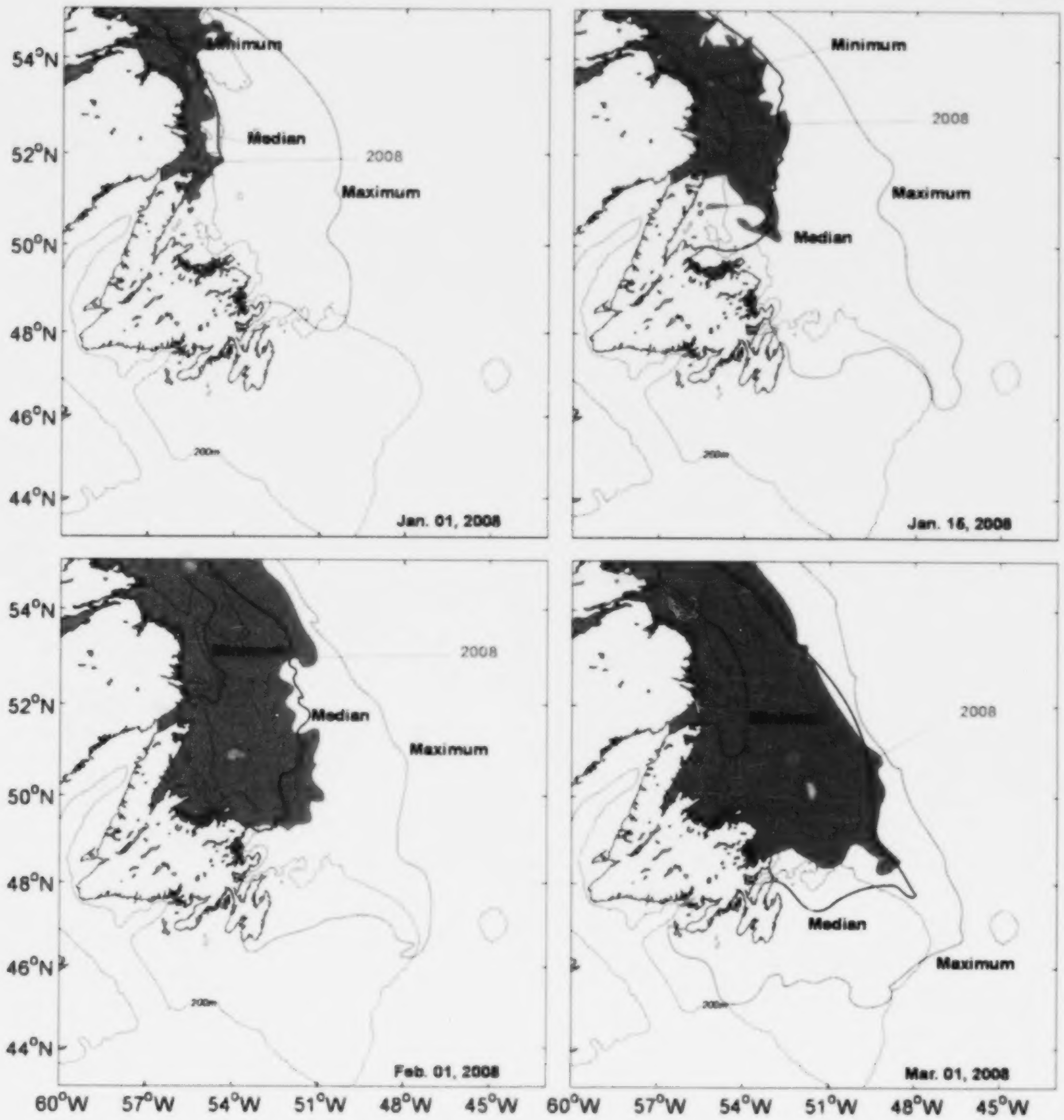
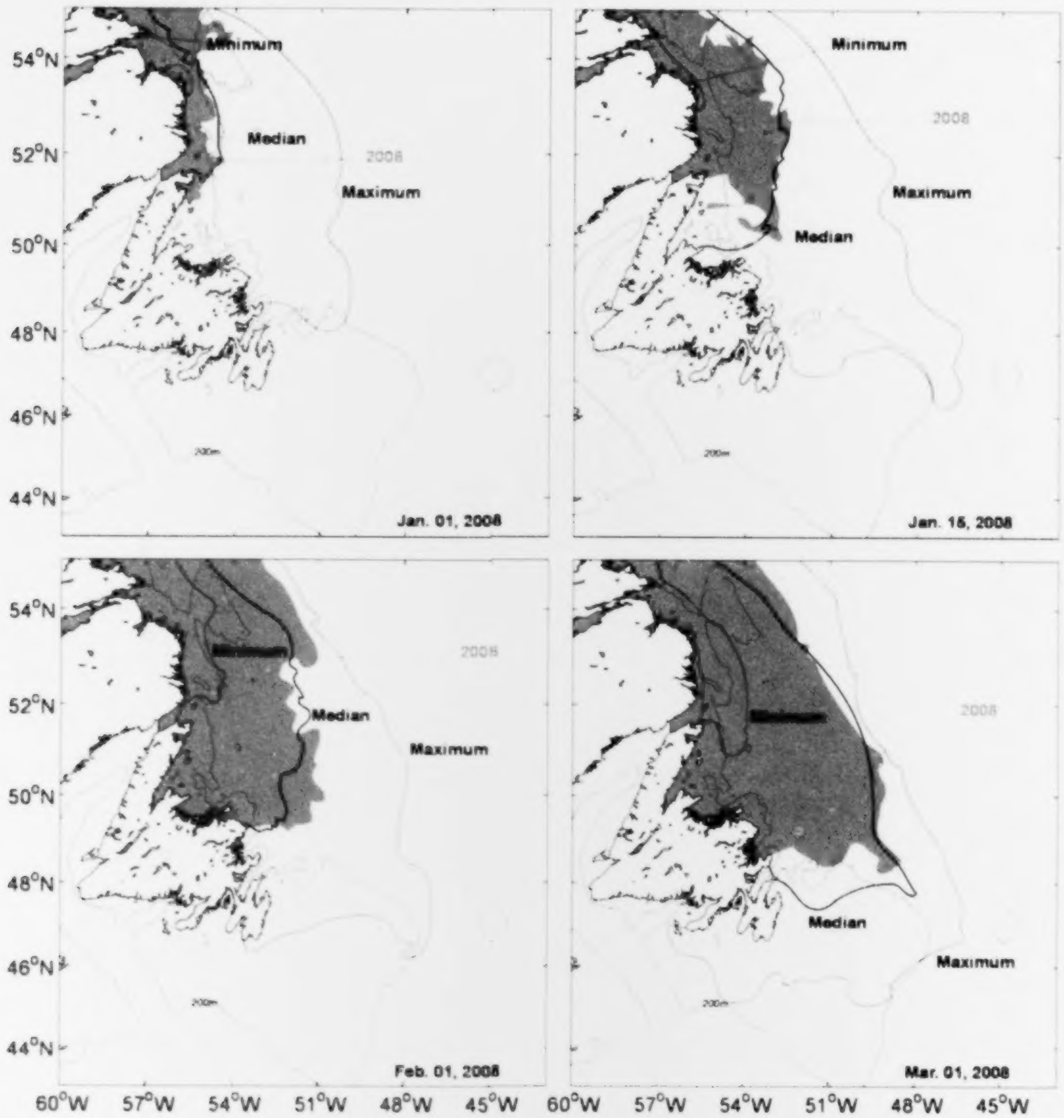


Fig. 8A. The location of the ice (shaded area) January to March 2008 together with the long-term (1971-2000) minimum, median, and maximum positions of the ice edge off the coasts of Newfoundland and Labrador. The positions of the ice edge in the Gulf of St. Lawrence are omitted in this figure.



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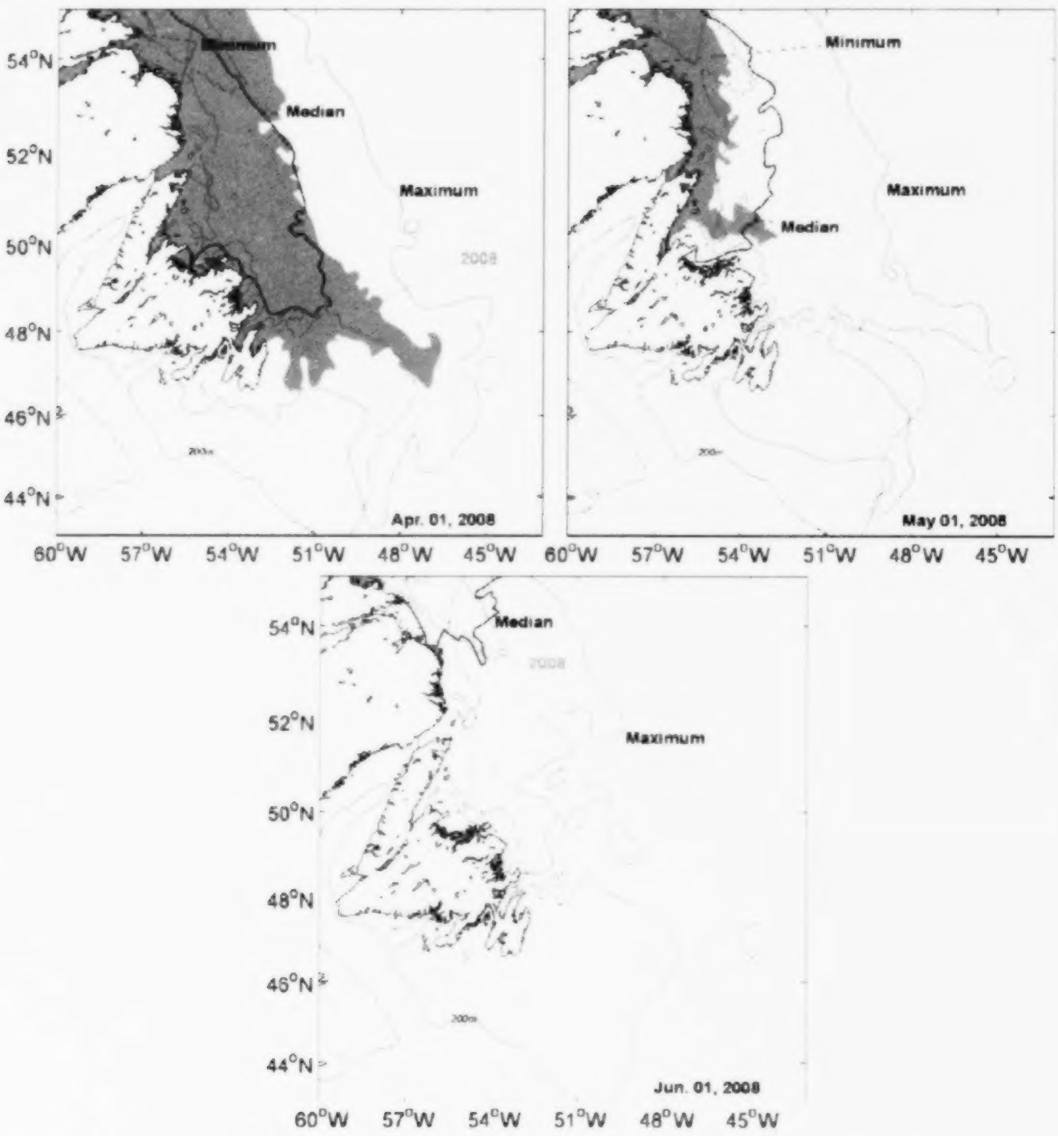
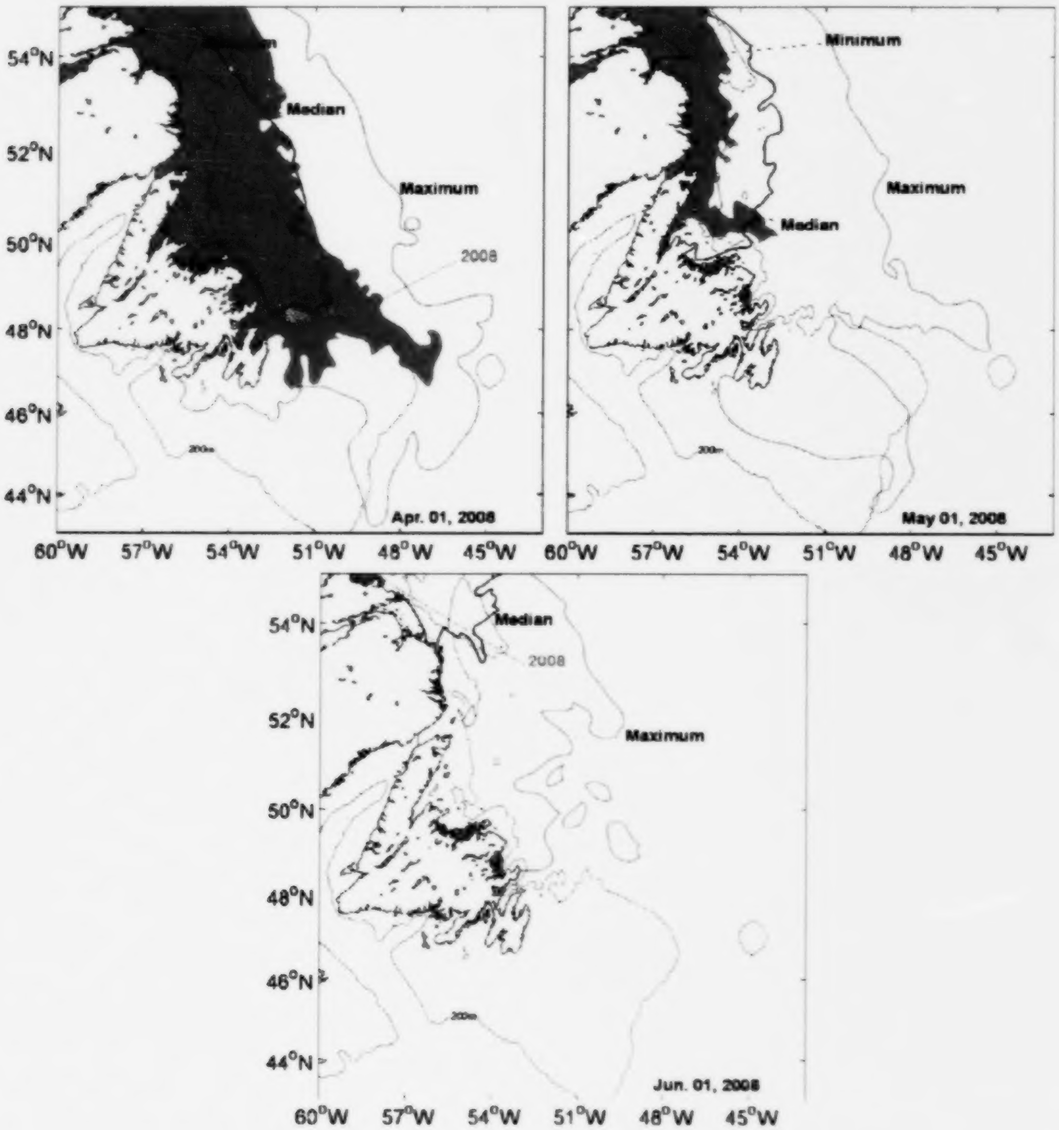


Fig. 8B. The location of the ice (shaded area) between April to June 2008, together with the long-term (1971-2000) minimum, median, and maximum positions of the ice edge off Newfoundland and Labrador.



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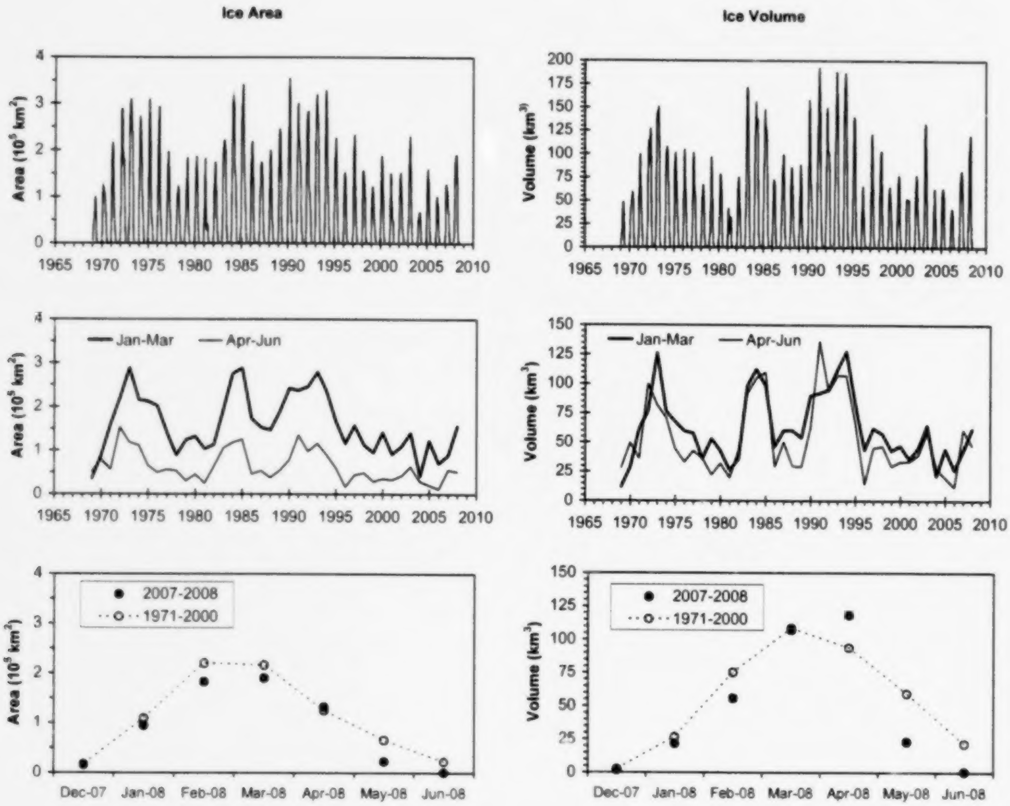


Fig. 9. Time series of the monthly mean ice area off Newfoundland and Labrador between 45°N-55°N (top panel), the average ice area during the usual periods of advancement (January-March) and retreat (April-June) (middle panel), and the comparison of the monthly areas and volumes to the 1971-2000 means (bottom panel).

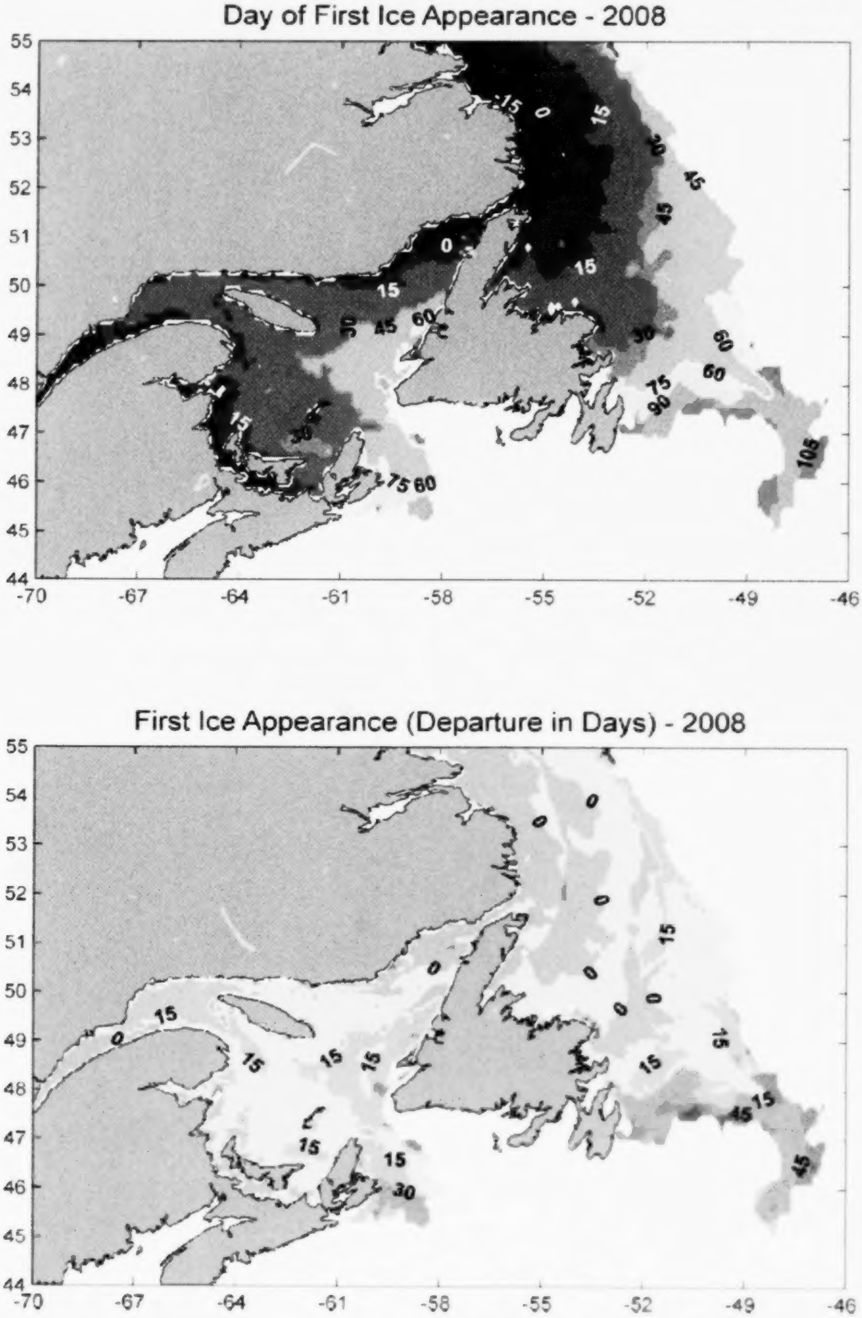
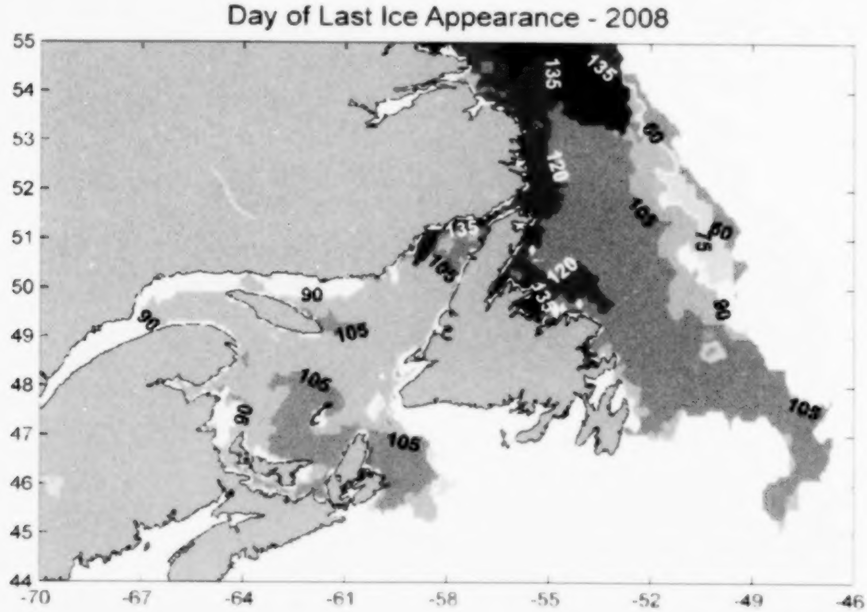


Fig. 10. The time when ice first appeared during 2008 in days from the beginning of the year (top panel) and its anomaly from the 1971-2000 mean in days (bottom panel). Negative (positive) anomalies indicate earlier (later) than normal appearance.



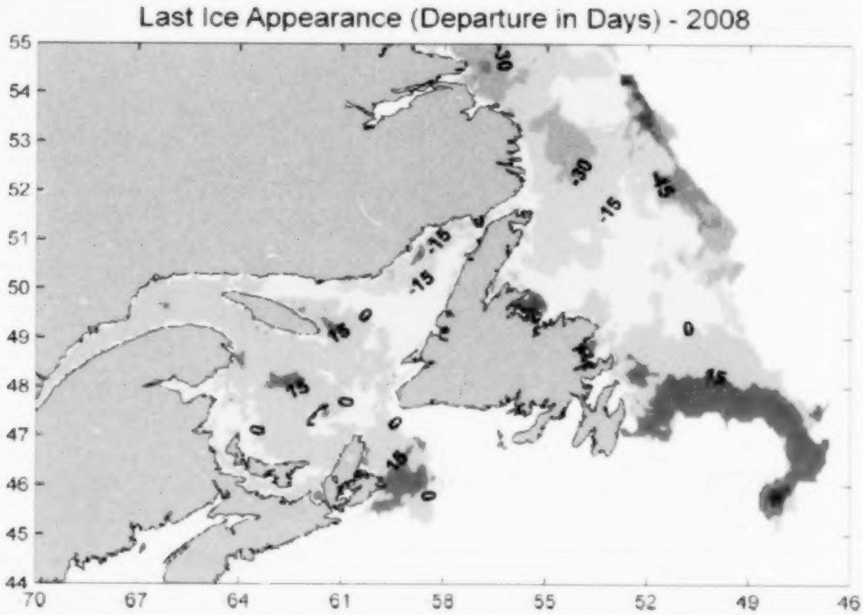
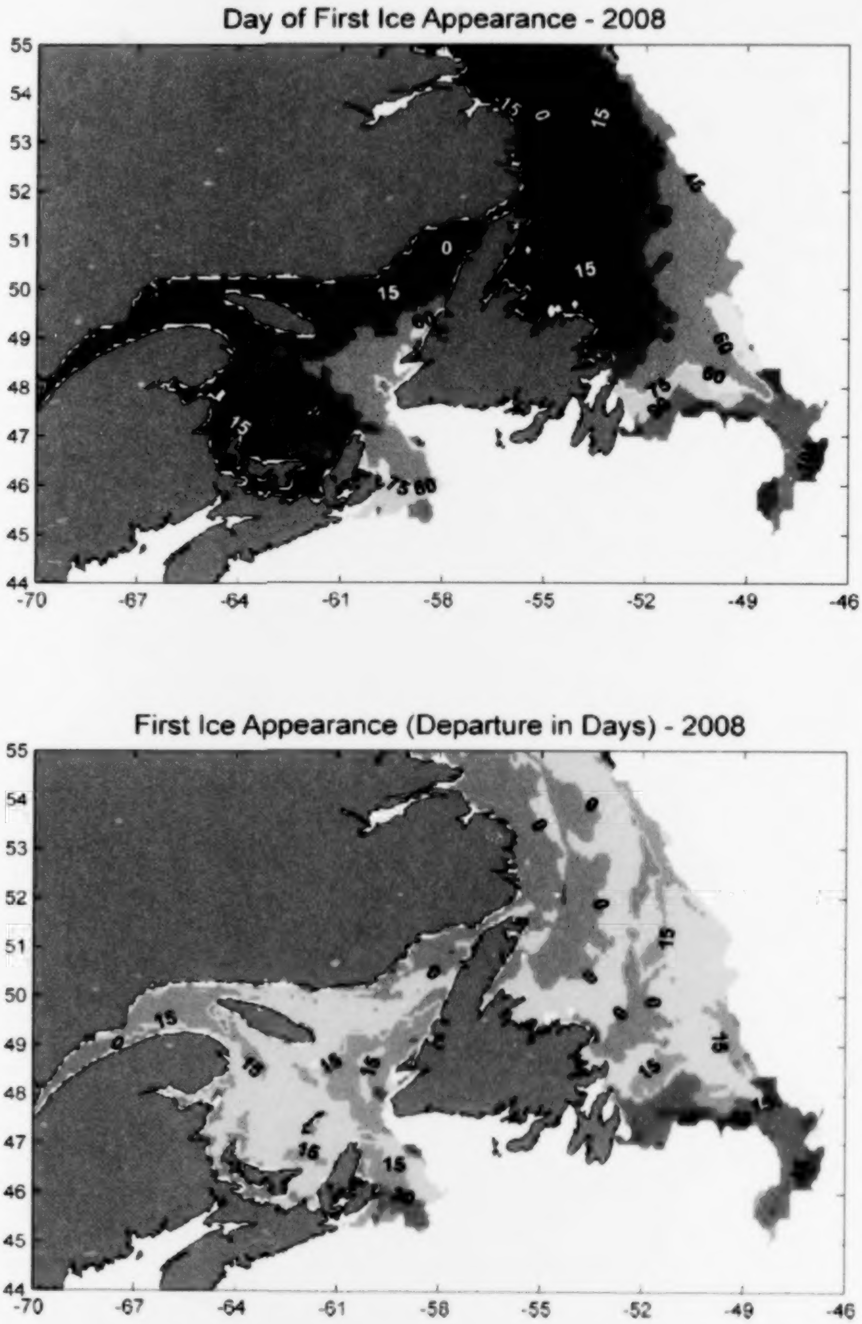


Fig. 11. The time when ice was last seen in 2008 in days from the beginning of the year (top panel) and its anomaly from the 1971-2000 mean in days (bottom panel). Positive (negative) anomalies indicate later (earlier) than normal disappearance.



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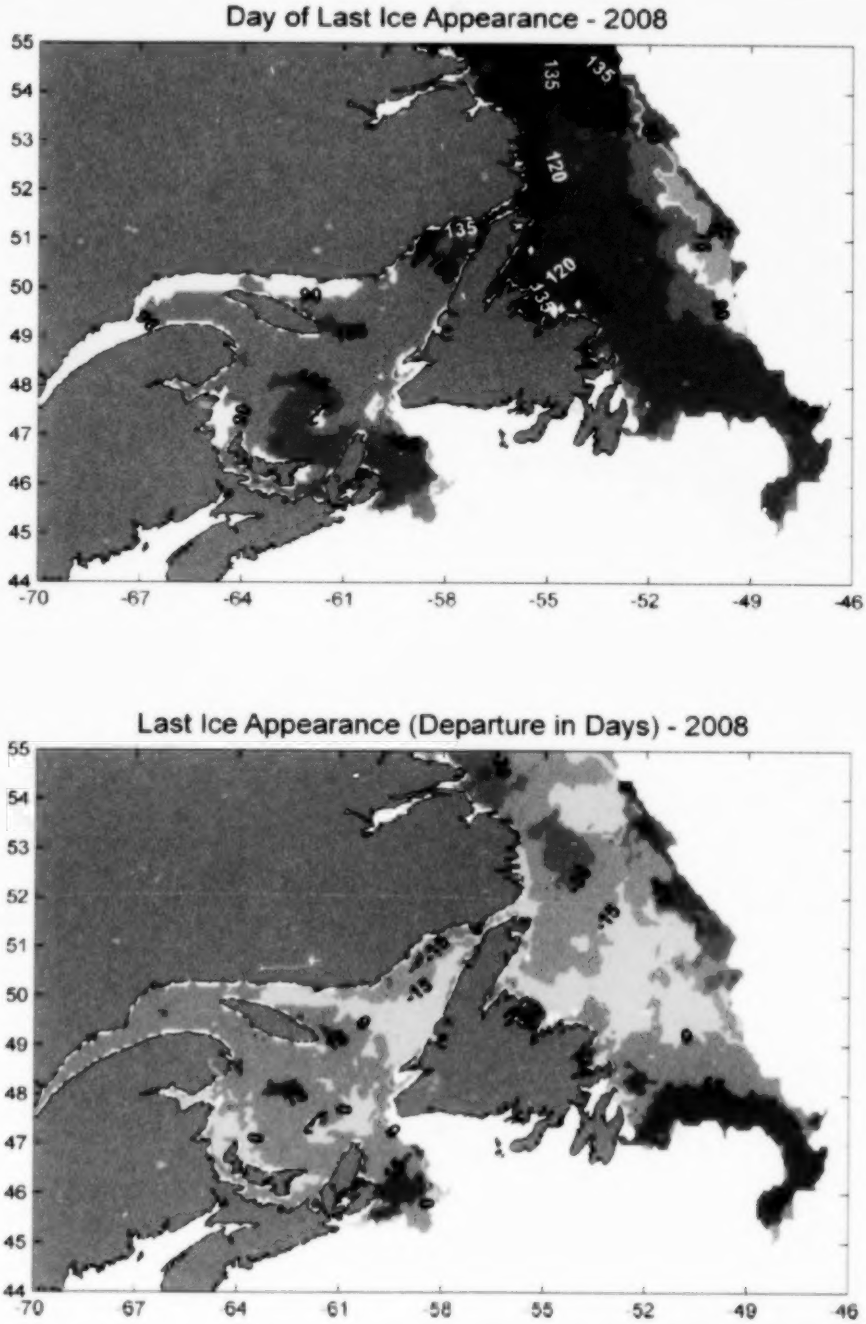

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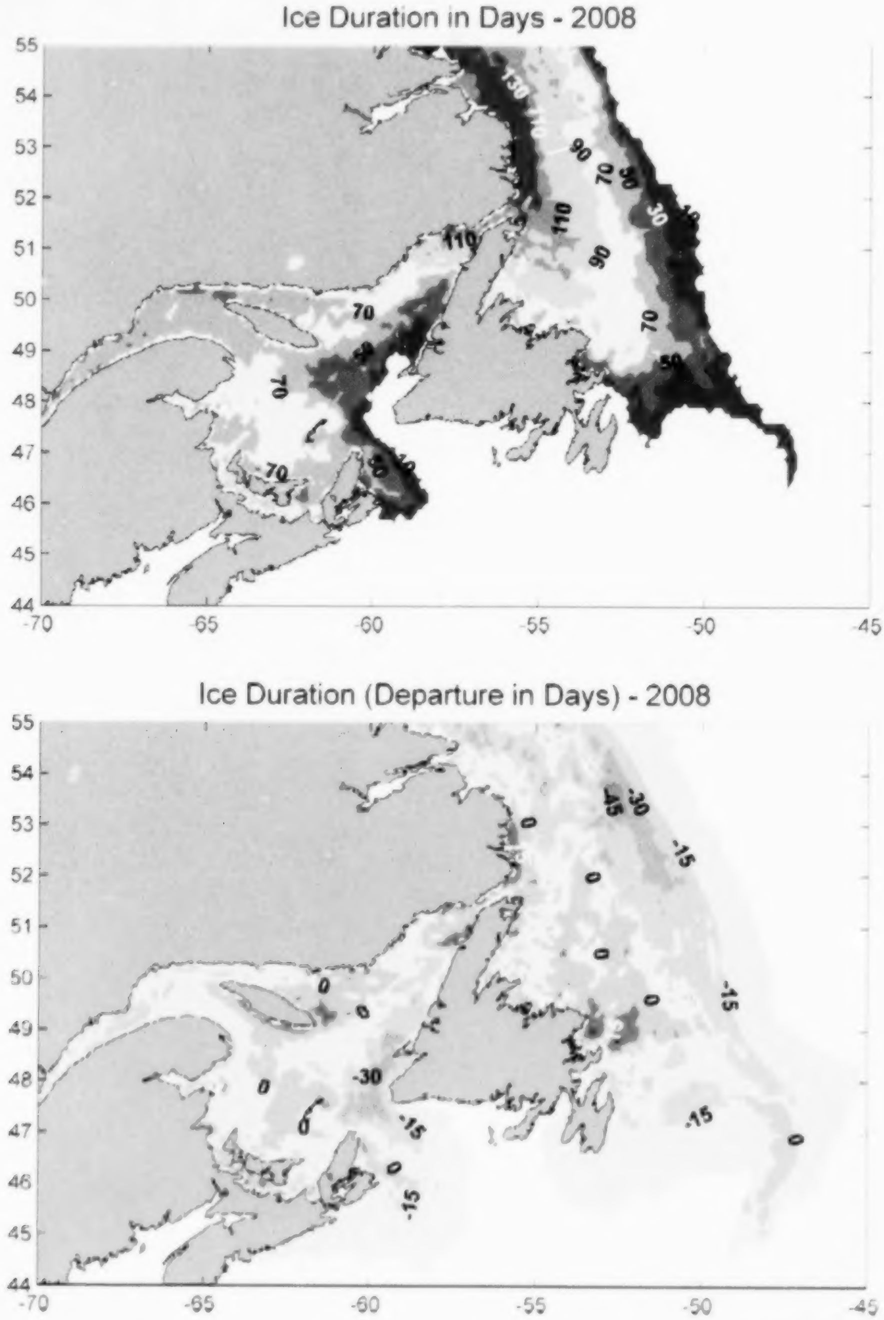


Fig. 12. The duration of ice in days (top panel) during 2007 and the anomalies from the 1971-2000 mean in days (bottom panel). Positive (negative) anomalies indicate durations longer (shorter) than the mean.

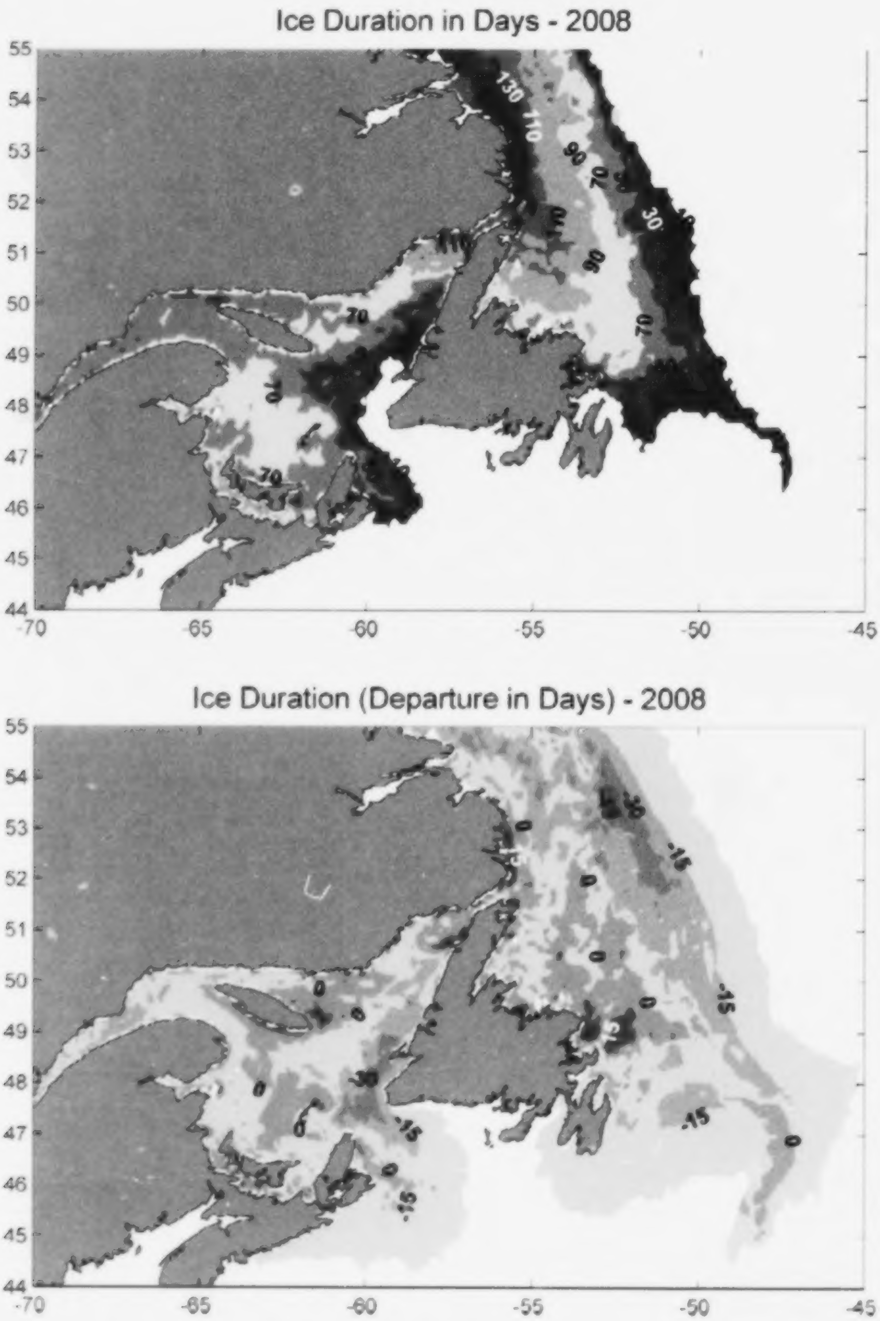
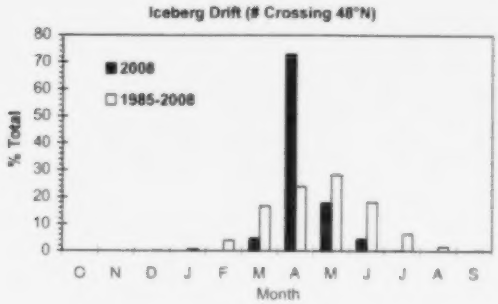
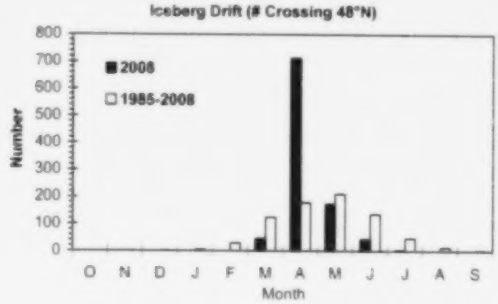


Fig. 12. The duration of ice in days (top panel) during 2007 and the anomalies from the 1971-2000 mean in days (bottom panel). Positive (negative) anomalies indicate durations longer (shorter) than the mean.





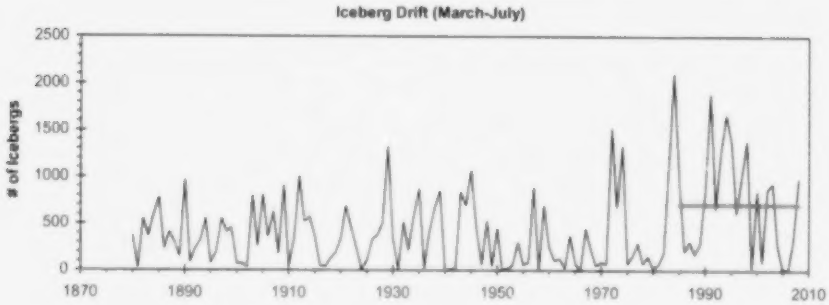


Fig. 13. The number of icebergs crossing south of 48°N during the iceberg season 2007/2008 expressed as a percent of the total and as absolute counts by month compared to the mean during 1985-2008 (top panel), and the time series of total number of icebergs observed during March to July (bottom panel). The thick grey line in the bottom panel shows the 1985-2008 average number of icebergs.

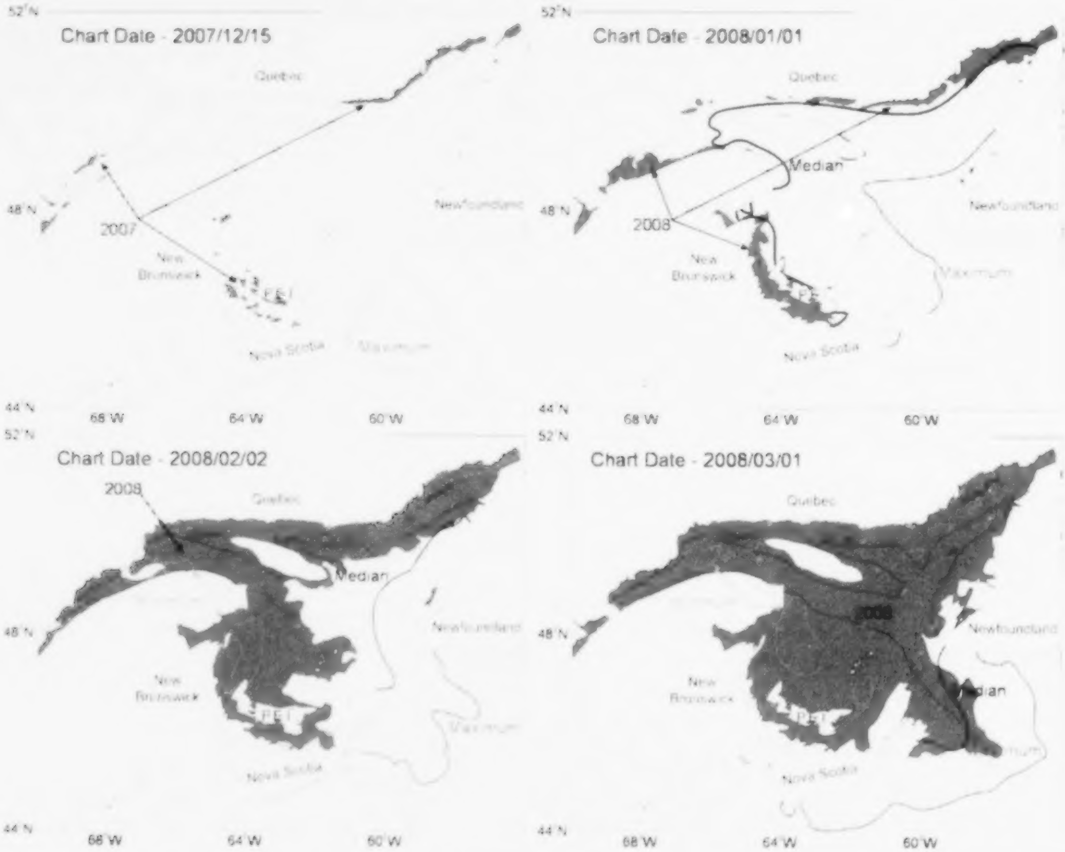


Fig. 14. The location of the ice (shaded area) between December 2007 and March 2008 together with the long-term (1971-2000) minimum, median, and maximum positions of the ice edge in the Gulf of St. Lawrence and Scotian Shelf.

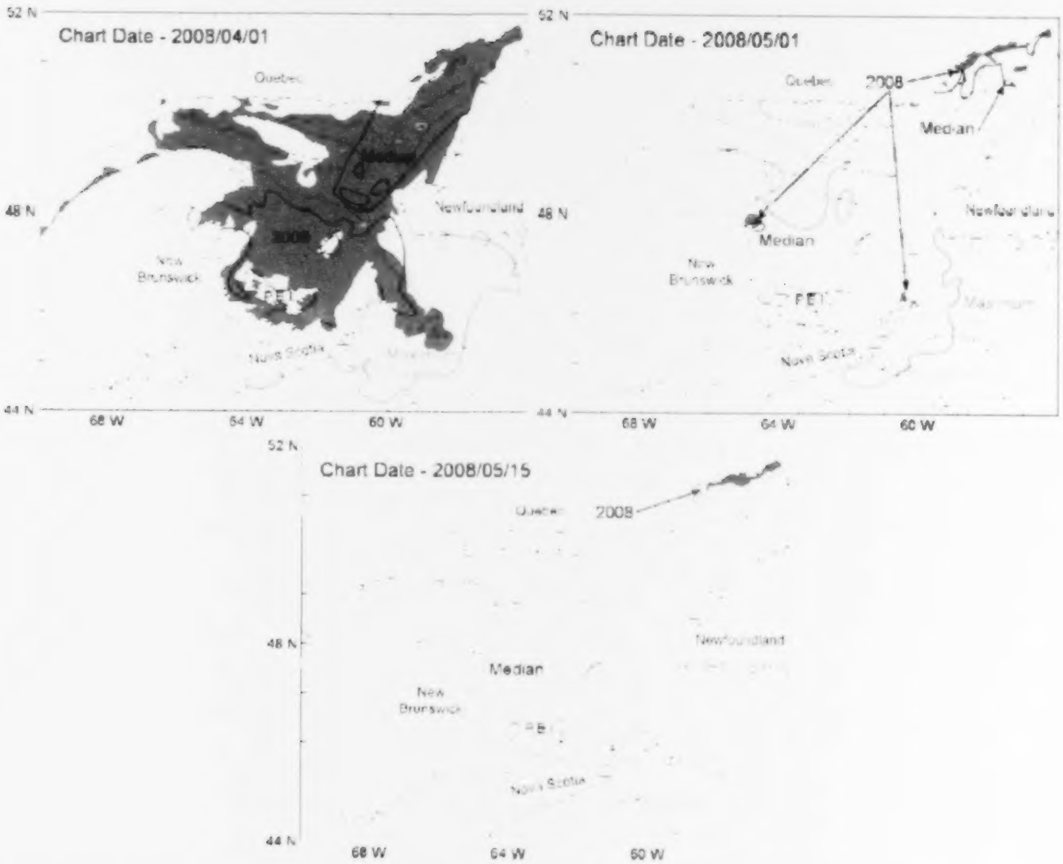


Fig. 14. continued. The location of the ice (shaded area) between April and May 2008, together with the long-term (1971-2000) minimum, median, and maximum positions of the ice edge in the Gulf of St. Lawrence and Scotian Shelf.

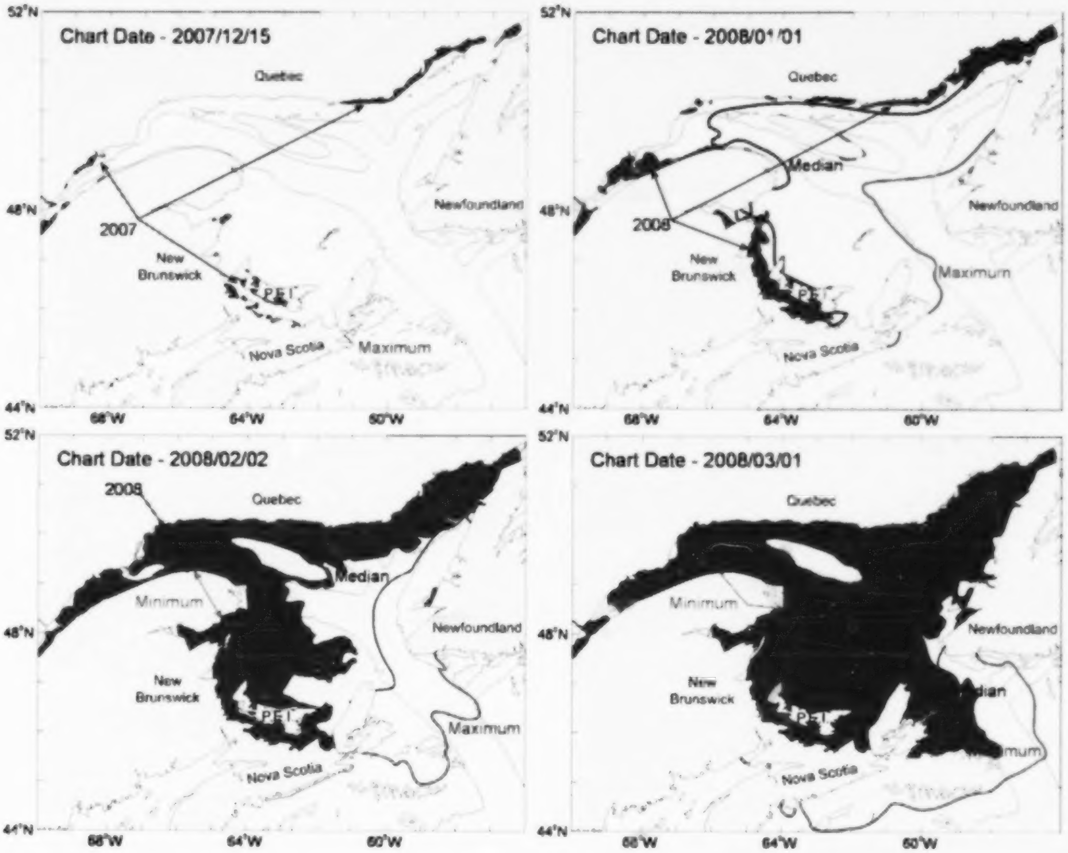


Fig. 14. The location of the ice (shaded area) between December 2007 and March 2008 together with the long-term (1971-2000) minimum, median, and maximum positions of the ice edge in the Gulf of St. Lawrence and Scotian Shelf.

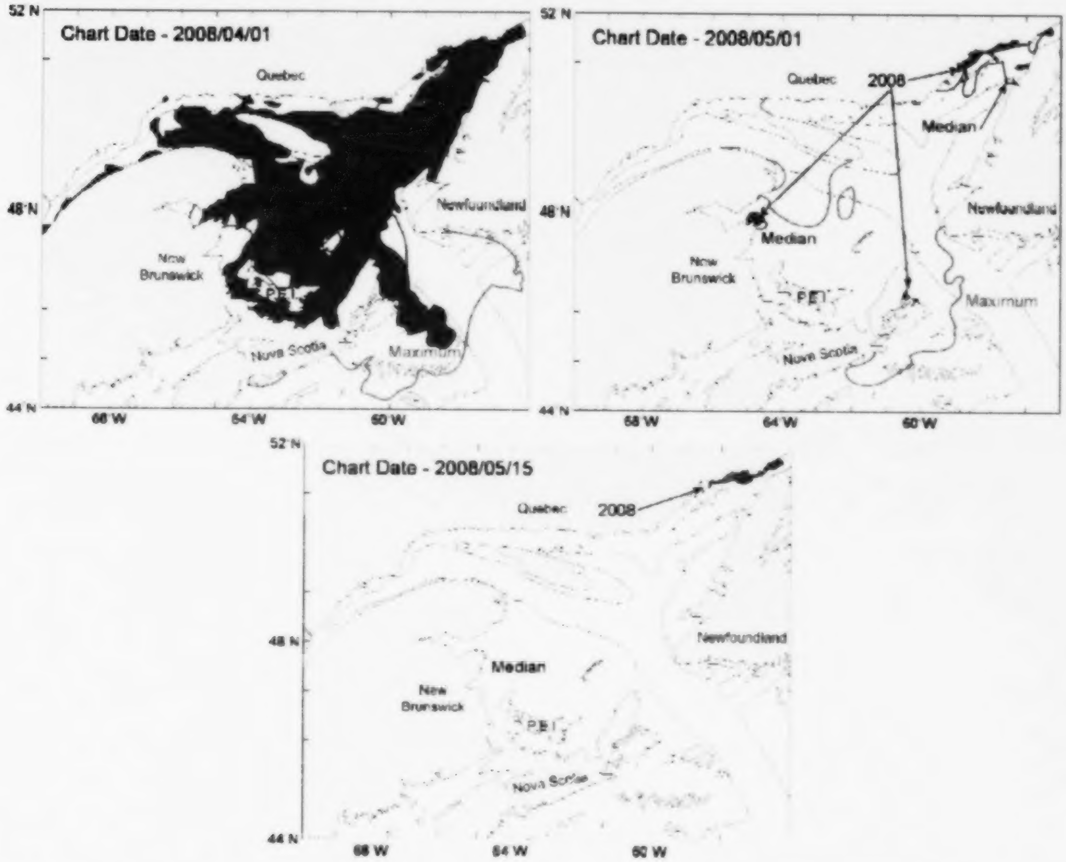


Fig. 14, continued. The location of the ice (shaded area) between April and May 2008, together with the long-term (1971-2000) minimum, median, and maximum positions of the ice edge in the Gulf of St. Lawrence and Scotian Shelf.

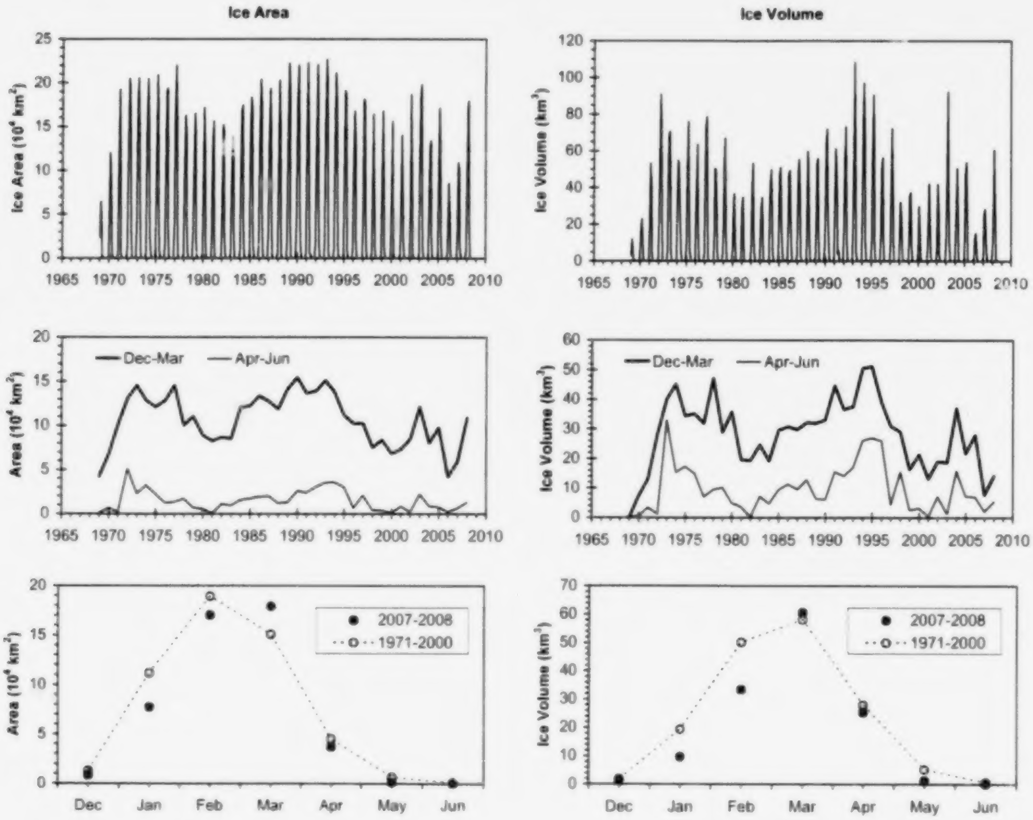


Fig. 15. Time series of the monthly mean ice area for the Gulf of St. Lawrence (top panel), the average ice area during the usual periods of advancement (December-March) and retreat (April-June) (middle panel), and the comparison of the monthly areas and volumes to the 1971-2000 means (bottom panel).

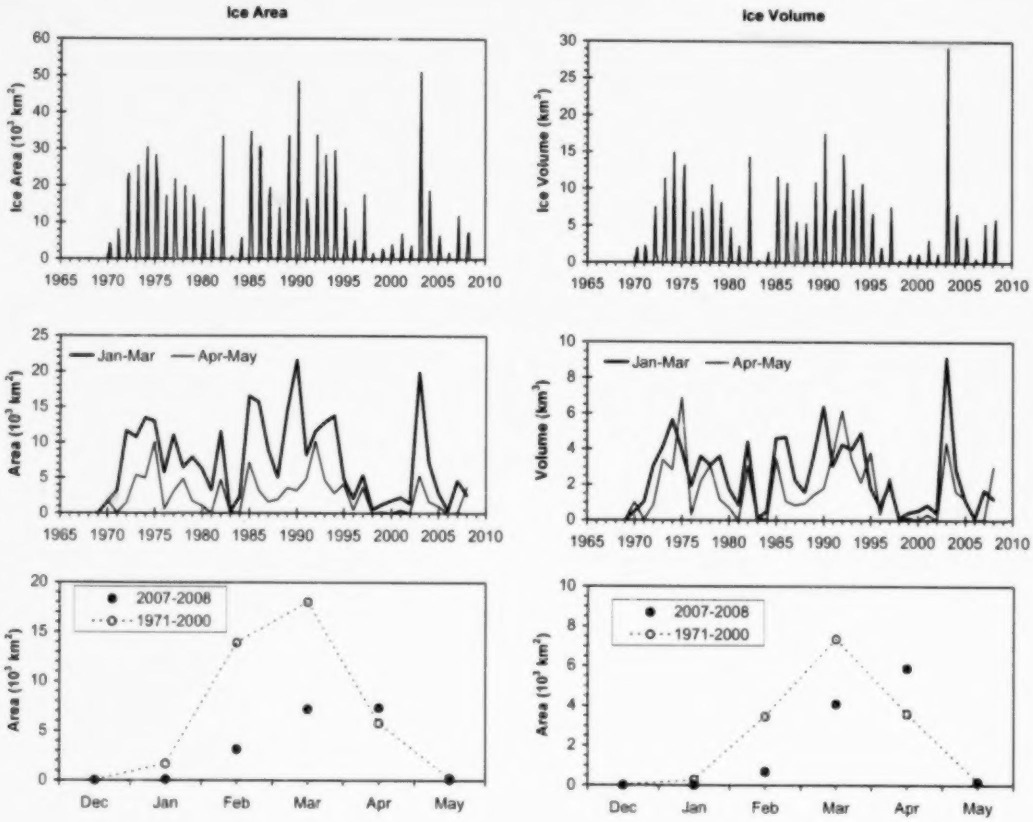


Fig. 16. Time series of the monthly mean ice area for the Scotian Shelf (top panel), the average ice area during the usual periods of advancement (January-March) and retreat (April-May) (middle panel), and the comparison of the monthly areas and volumes to the 1971-2000 means (bottom panel).

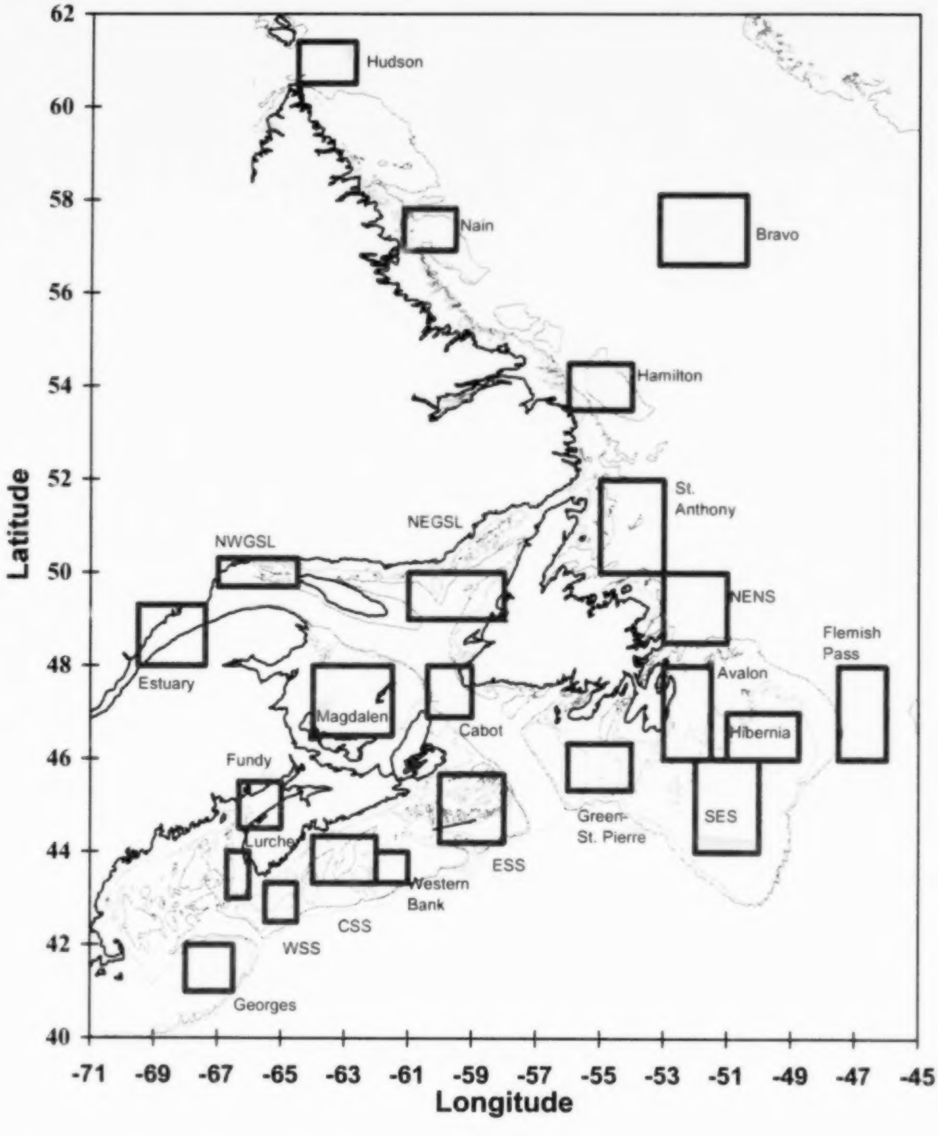


Fig. 17. The areas in the Northwest Atlantic used for extraction of sea-surface temperature.

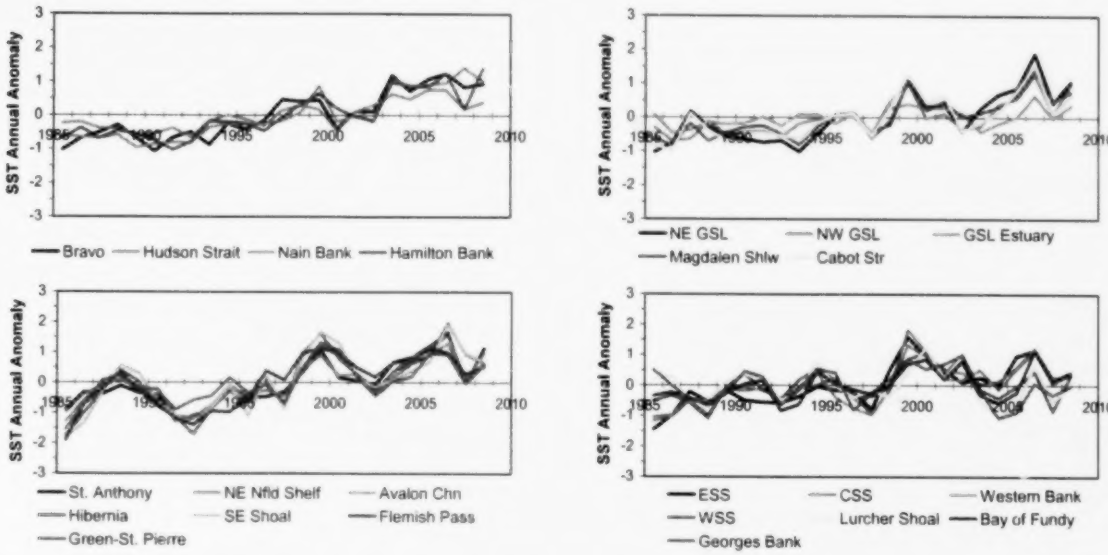


*Fig. 18. The annual sea surface temperature anomalies derived from satellite imagery compared to their long-term means. Pathfinder estimates were used for September 1985 - May 2003. Estimates for June 2003 - December 2008 were from the remote sensing laboratory, Ocean Research and Monitoring Section of the Ecosystem Research Division at the Bedford Institute of Oceanography (Dartmouth, NS). These values were adjusted by the regression Pathfinder=0.976*ORMS+0.46 based on a comparison between overlapping Pathfinder-ORMS data.*

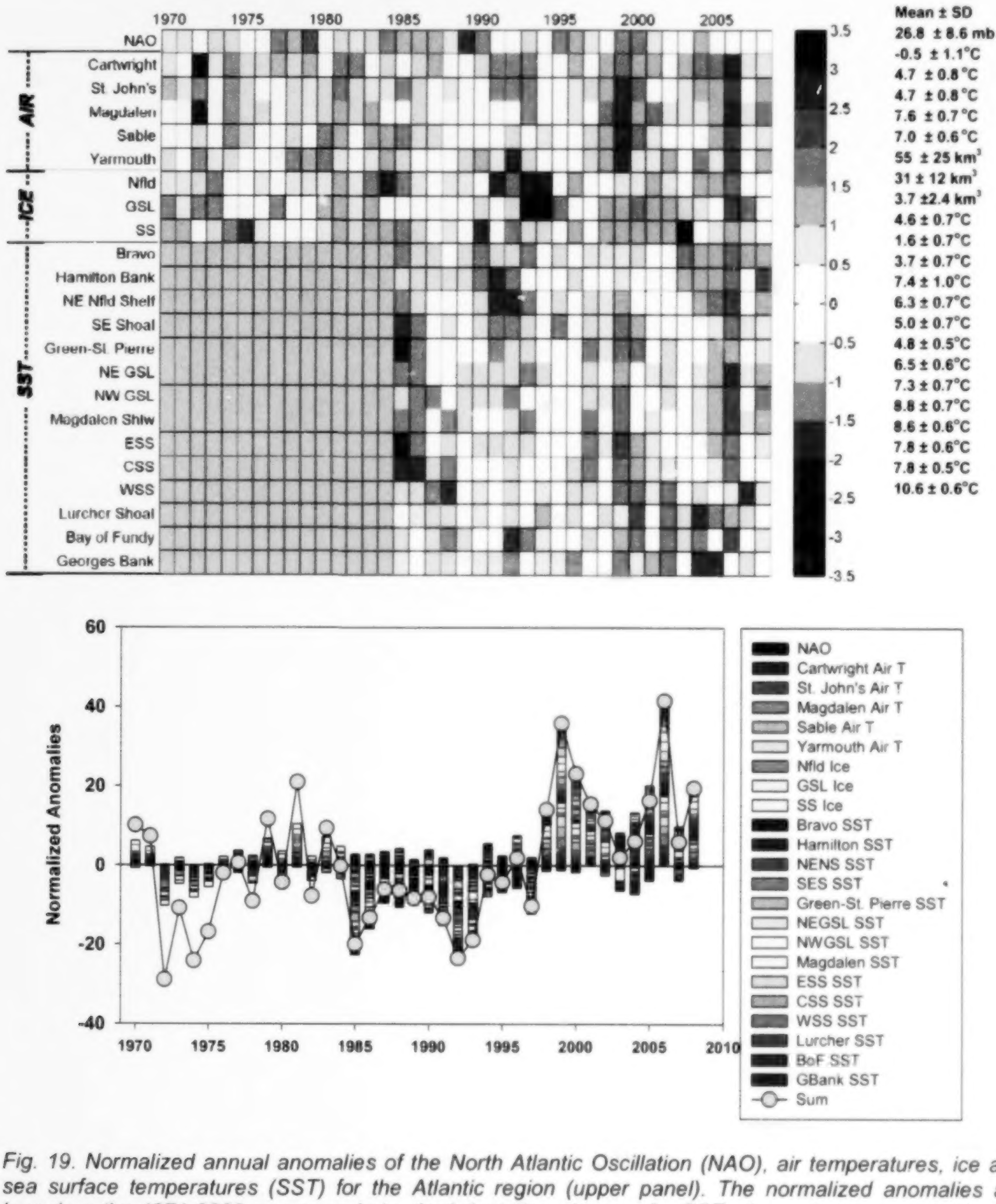


Fig. 19. Normalized annual anomalies of the North Atlantic Oscillation (NAO), air temperatures, ice and sea surface temperatures (SST) for the Atlantic region (upper panel). The normalized anomalies are based on the 1971-2000 means and standard deviations (except for SST where all data are used). The scale represents the number of standard deviations an anomaly is from normal; blue indicates below normal, red above normal. The signs of the ice volume and NAO series have been reversed since reduced ice cover, and a negative NAO represent warmer than normal conditions. The contributions of each of the normalized anomalies are shown as a bar chart and their summation as a time series (grey circles, black line; lower panel).